INTERRELATIONS OF THE FOSSIL FUELS.

I.

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(*Read April 14, 1916.*)

Peat and the Tertiary Coals.

Prefatory Note.—In an earlier treatise,[1] the writer considered some problems bearing upon the accumulation of coal in beds. Other, but closely related, problems will be considered here in the effort to ascertain how closely the fossil fuels, aside from petroleum, are related to each other in their physical and chemical characteristics as well as in their mode of accumulation. In preparing for these studies, the writer has travelled scores of thousands of miles in foreign regions to secure information respecting disputed localities and, in this land, he has made examinations in almost all of the coal-producing states. But life is short and distances are great; a man can gather little by direct study; to secure the knowledge necessary for intelligent discussion of the subject, he must collect and compare, as far as possible, the observations reported by others. This has been attempted; several thousands of reports, notes, memoirs and monographs have been read and the abstracts have been digested, in so far as they contained matter bearing on the problems in hand. All citations, except where otherwise stated, are at first hand.

Some may regard study after this fashion as wasted force, especially because the matters involved appear to possess little of economic interest; but the labor has been performed without compulsion and with no hope of reward, except that of criticism by

[1] "The Formation of Coal Beds," *Proc. Amer. Phil. Soc.*, Vol. L., pp. 1–116, 519–643; Vol. LI., pp. 423–553; Vol. LII., pp. 31–162.

those who may regard the work as defective and the conclusions as unsound. The study has been made solely to find solutions of problems which had perplexed the writer during more than 45 years. The results are presented, not because they are final, but in the belief that those students who take up the investigation anew at some future time, when knowledge shall have been increased, will find their labor lessened by this opening of by-paths in the literature; and equally in the hope that credit may be restored to some of the earlier students, whose work has been forgotten or ignored.

The autochthonous origin of coal is taken for granted in this work; argument in favor of that doctrine has been presented in the writer's "Formation of Coal Beds."

The various terms applied to fossil fuels have, in a general way, sufficiently definite significance. When one hears the words peat, brown coal, coal, anthracite, he recognizes each as referring to a substance with which he is familiar. Museums contain specimens from many localities, properly labeled, so that the names become for students thoroughly definitive. Tables of comparative analyses are given in textbooks, which mark off the limits of the several substances with ample distinctness. It is true that in most textbooks and in most lecture courses there is proper though somewhat incidental statement that the specimens represent, for the most part, what may be termed typical forms, and that from each type in each direction to the next the transition is practically imperceptible. Yet that that conception lacks concreteness, the more so because each appears to be characteristic of a certain stage in the earth's history. But the names are those of groups, each comprised of members differing greatly in chemical and physical features; and there are strange overlappings, for in the groups less advanced chemically, one finds substances very similar to some in the more advanced, while in the latter he occasionally meets with forms almost indistinguishable from some of the former.

Since the extent of chemical change, as a rule, increases with the age of the deposit, it is most convenient to consider the fuels in the order of their occurrence in time.

PEAT.

Peat is the familiar accumulation of more or less changed vegetable matter observed in localities sufficiently moist. It is most abundant in Pleistocene and Recent deposits, but a very similar material occurs in the Tertiary and, even in the Carboniferous, one finds a substance, which in hand specimens can hardly be distinguished from well-dried peat.

Conditions Requisite for Accumulation.—As asserted long ago by Alex. Brongniart, constant supply of moisture in considerable quantity is a prerequisite for growth of peat. Ponds and shallow lakes in glacial drift have been favorite localities in the northern part of the temperate zone, where deposits vary in extent from a few square rods to several scores of square miles. Areas of deep water are made shallow by accumulating animal and vegetable remains, largely of humble types, and eventually become filled with normal peat. But such deposits are, individually, of small extent, though they are so numerous that, collectively, they cover much of the formerly glaciated surface within North America and Europe. Peat areas of greatest extent are those originating on coastal plains or on those bordering rivers, where the sluggish drainage is checked readily by petty obstacles and small patches of swamp become united until a great space has been occupied. Some deposits of this type have an area of many hundreds of square miles.

Peat has provided fuel for much of northern Europe during centuries and the literature with reference to it is voluminous; but it has no economic importance within the tropics, so that definite statements respecting its occurrence are comparatively few. Explorers naturally were concerned more with geography and anthropology, so that one finds usually little aside from incidental statements to the effect that a region is swampy, boggy and difficult to traverse. But more than one hundred years ago, Jameson[2] stated that Anderson had received peat from Sumatra. Certainly the conception that true peat is confined to the temperate zones is erroneous. Livingstone in 1858 and 1866 presented abundant evi-

[2] R. Jameson, "An Outline of the Mineralogy of the Shetland Islands, and of the Island of Arran," Edinburgh, 1798, pp. 151–153.

dence of its existence in equatorial Africa. Wall and Sawkins in 1860 found peaty deposits on the island of Trinidad, which even after desiccation at 300° F. contained 35 per cent. of organic matter. In 1870, Hartt reported his discovery of peat in the state of São Salvador, S.L. 10°, as well as in the state of São Paulo, both in Brazil. Brown described peaty deposits in the Demarara region; "from Santa Rosa on through the Staboots, the head of the Barabara River, there are many tracts of open land, composed of black bog-mud formed by decayed vegetables and covered with a growth of rank sedges and rushes." Some portions of these "savannas" are permanent swamps, in which the Ita palm, *Mauritia flexuosa,* is one of the prominent trees, rising to the height of 60 feet. Harrison, in discussing the same region, says that peat occurs in many of the low-lying coast lands, where it is from 1 to 10 feet thick, though usually not exceeding 4 feet. Considerable portions of this "pegass" land are covered with the Aeta palm.[3]

Long ago, Lyell described the general features of the Dismal Swamp and of the cypress swamps of the lower Mississippi River, both of which were discussed in detail by Shaler at a later date. Kuntze[4] in 1895 described the vast wooded swamp, a mass of peat extending for 3 degrees of latitude along the Lourenço River of Brazil. The conditions in Florida, where the peat areas are great and the deposits often very thick, have been described in detail by Harper, and several observers have made note of the peat in Bermuda. Livingstone, Cameron, Lugard and Miss Kingsley have presented proof that peat is abundant in equatorial Africa.[5]

During the progress of the Dutch explorations in Sumatra, 1891, Koorders observed a great Flachmoor covered with a 30-meters-high mixed forest growing on peat, which Larive's measurements

[3] G. P. Wall and J. G. Sawkins, "Geology of Trinidad," London, 1860, pp. 62, 63; C. F. Hartt, "Geology and Physical Geography of Brazil," Boston, 1870, pp. 365, 509; C. B. Brown, "Physical, Descriptive and Economic Geology of British Guiana," Geol. Survey, London, 1875, pp. 34, 91; J. F. Harrison, "Pegass of British Guiana," *Quart. Journ. Geol. Soc.,* Vol. LXIII., 1907, p. 292.

[4] O. Kuntze, "Geogenetische Beiträge," Leipzic, 1895, pp. 67, 68.

[5] For detailed statement of these observations in tropical and subtropical regions, see "Formation of Coal Beds, II.," *Proc. Amer. Phil. Soc.,* Vol. L., 1911, pp. 565–573.

proved to be 9 feet thick. Examination, microscopical and chemical, showed that this peat has structure and composition wholly similar to the peat of Europe, though the plants from which it is derived are different.[6]

Molengraaff[7] studied central Borneo in 1893–94. On many pages he notes the presence of marshes along the larger rivers and describes them as boggy. These marshes in many cases are densely wooded though frequently covered with water during several months in succession. A considerable deposit of peat was seen near the Tebaoeng River. In ascending Babas Hantoe, one of the Madi mountains, he reached, at 500 meters above the sea, an extensive plateau, on which the forest contains many conifers, these increasing upward until at 700 meters they were paramount. There a soft soil had been reached, mosses had appeared and the character throughout was that of a forested swamp. The deeply trodden narrow path wound among wet spongy cushions covered with moss until at 1,000 meters the area was a genuine morass and advance could be made only by leaping from the root of one tree to that of another. The altitude is not sufficient to remove the locality from tropical conditions, as this is almost directly under the equator. On the other side of the mountain, he descended into a valley, which at first showed patches of marshy forest with peat. Farther down, the peat patches became continuous and he soon recognized that the whole of this valley and probably the whole Madi plateau are covered with a marshy forest, standing in a thick layer of peat, which consists of the half decayed remains of all kinds of trees, shrubs and mosses, a true tropical peat bog; but, like tropical fens generally, it is composed chiefly of remains of trees, thus contrasting with fens of temperate zones, which originate so frequently from mosses and a limited variety of shrubs. The yellow-brown fen water from this peat area flows into the Tebaoeng River.

Koorders, as cited by Potonié, reported that, in old Javan and

[6] H. Potonié, "Die Enstehung der Steinkohle und der Kaustobiolithe überhaupt," 5te Aufl., 1910, pp. 152–160.

[7] G. A. F. Molengraaff, "Geological Explorations in Central Borneo, 1893–94," Leiden, 1902, pp. 83, 84, 307, 310. The citations are from the edition in English; the edition in Dutch was published in 1899.

Sumatran forests, where hard woods grow, fallen trees are numerous, which though decades old are still in condition good enough for export. Molengraaff gives an illustration more remarkable, because the conditions are not constant. The Lake district of the Upper Kappewas River is merely the overflow area during flood time. The lakes contract during the dry season, leaving only shallow channelways in which fish accumulate. The Malays gather in camps to harvest the fish and the camp fires frequently spread, causing great destruction in the forest. In one portion of this district, a great "submerged" forest remains, composed of medium-sized charred stumps, in varying stages of decay and all broken off at approximately the same height. A sprinkling of younger trees was seen, but owing to the unfavorable conditions—flooding and fires—the forest cannot recover. This locality was described by Ida Pfeiffer in 1846, when the features differed little from those observed by Molengraaff, almost half a century later. Evidently, decay of rooted stumps may be as slow under the equator as in temperate regions.

Wichmann[8] gathered available information respecting peat deposits in the Indian archipelago, summarizing observations by Junghuhn, Koorders, Molengraaff, Machielson, Schwaner, Teyssmann, Van Nouhys and himself. The largest fen in Java is in Samarang; about 2,500 hectares have been brought under cultivation but not less than 1,500 still remain as swamp. Borings at one locality show that the peat is from 30 to 31 meters thick and "peat islands" have risen in it at various times. The Javan peat is an inferior fuel as it contains much ash; that from Kapogan has 27 per cent.

Very many swamps within the east coast residency of Sumatra have been drained and placed under cultivation; but much still remains untouched. A great fenland of 80,000 hectares, between the Siak and Kampar rivers, has been known long time and it has been described by Koorders, botanist to the Ijzerman expedition of 1891. As Wichmann presents the matter, peat is evidently a commonplace in Sumatra. He refers to Molengraaff's observations in central Borneo. W. J. M. Machielson found fens along several rivers in another portion and C. A. L. M. Schwaner reported them from

[8] C. E. A. Wichmann, "The Fens of the Indian Archipelago," *K. Akad. Wetensch.*, Amsterdam, Vol. XII., 1909, pp. 70–74.

several localities in the south and east divisions, where all the streams are blackwater. Some of the Borneo peat is very good, that collected by J. W. Van Nouhys containing only 4.58 per cent. of ash.

A very great part of the fenland in the Archipelago has been drained and converted into rice, sugar cane or tobacco plantations, but Wichmann estimates that the area of existing fens exceeds 1,000,000 hectares or more than 3,800 square miles. The uniformity of climatal conditions prevents the variations observed in fens of colder regions. The structure, in Wichmann's opinion, resembles that seen in the Coal Measures, where roots of *Lepidodendron* and *Sigillaria* are found in the floor of coal beds; so in the tropical fens, the trees are rooted in the subjacent clay. As accumulation of peat does not choke the trees rapidly, these frequently remain erect in the peat.

It would seem to be sufficiently evident that a hot climate offers no hindrance to the accumulation of peat, if only the conditions exist which are required for that accumulation in a cool climate.

Even a very severe climate does not prevent the growth of peat. Nathorst[9] visited the Renntier-tal of Spitzbergen in 1882 and saw there, resting on the river débris, 0.25 meter of clayey peat underlying 2 meters of peat: he cites Gunnar Andersson as stating that the upper division consists chiefly of brown moss, but that some layers are crowded with leaves of *Salix polaris*. Nathorst found a leaf of *Salix reticulata* in the underlying impure peat. Andersson believes that peat-formation has ceased in Spitzbergen and that the deposits are relics of a less cold period. Be that as it may, there can be no doubt that bogs are numerous, though in many instances they are thin. The writer in 1904 found enough peat on both sides of Advent bay, N.L. 78°, to make walking not too attractive and there was living vegetation on the surface in many places. A. E. Stevenson reported that the black mud is more than knee-deep for considerable distances along the shore of Icefiord to more than 12 miles south from below Advent bay. Peat was seen on Bell sound.

[9] A. G. Nathorst, "Beiträge zur Geologie der Bären Insel, Spitzbergen, und des König-Karl. Landes," *Bull. Geol. Inst. Univ. Upsala*, Vol. X., 1910, p. 403.

Russell[10] has described conditions on the tundra and in the interior of Alaska. He says that "without exaggeration, it may be stated that the whole of Alaska, excepting the steepest rock slopes and the tops of high mountains, is covered with a dense carpet of moss." The reported thickness of peat on the tundra is from 2 to 150 even to 300 feet. The peat is growing, though the depth to frozen material is only from 8 to 14 inches. Capps[11] has described an Alaskan peat deposit, exposed in a bluff for more than a mile. The peat, 39 feet thick and resting on unconsolidated glacial till, is fibrous, with abundant stumps and roots, but probably consists mostly of *Sphagnum*. The mass is divided at 7 feet from the top by 2 feet of white volcanic ash. The surface beyond the edge of the bluff is covered with a thick coat of *Sphagnum* and supports a dense forest of spruce with little undergrowth. The peat, ash and till are permanently frozen at a few inches back from the edge of the bluff, though that is subjected to the long hours of summer sunshine. Even the surface is frozen at a depth of 6 inches in early July.

The arrangement of roots shown by spruce trees growing at the edge of the bluff as well as by the stumps, which compose a great part of the deposit, is wholly unlike that ordinarily observed. Spruce growing on solid ground, frozen or not, has radial roots, parallel with the surface and penetrating only a few inches; but, at this White River locality, the roots of trees growing on the edge of the bluff and those of stumps buried at different levels in the peaty mass have a very different arrangement. Instead of a single, flat-based set of radial roots, these trees all show a central stem, often several feet long, from which roots branch off at irregular intervals, with an upper set of roots near the surface, corresponding to those of the normal tree. Investigation proved that roots below the frost-line are still undecayed, though they differ in color from the uppermost set of radial roots and evidently are no longer active. Capps reached the conclusion that, in each case, the seedling spruce, having established itself on the mossy soil, sent out the normal radial roots; but

[10] I. C. Russell, "Notes on the Surface Geology of Alaska," *Bull. Geol. Soc. Amer.*, Vol. I., 1890, pp. 125, 126, 129.

[11] S. R. Capps, "An Estimate of the Age of the last great Glaciation in Alaska," *Journ. Washington Acad.*, Vol. V., 1915, pp. 108–115.

the rapidly thickening moss and consequent rising plane of frozen ground cut off nutriment from the existing roots, necessitating the formation of a newer set nearer the surface. He measured one tree, which had 24 inches of vegetable matter above the lowest horizontal roots. At 6 feet above the surface it had 373 annual rings, so that the growth of the peaty mass had been at the rate of one foot in about 200 years. One foot of the compact peat lower down represents a much longer period.

Tyrrell[12] has studied peat deposits in a great part of Canada. He notes that in northern Canada the peat, 10 to 12 feet thick, often rests on a plate of clear ice. The water for this came from springs below the permanently frozen ground and it favored the growth of peat mosses in summer. The peat of Canada, except in the southern portion, consists practically of undecomposed moss from top to bottom, as the intense cold prevents change, the lower portions being frozen. In the Klondike region, the moss layer is rarely more than 5 or 6 feet thick, but there may be below it a variable mass of "muck," a mixture of sand and vegetable matter, the latter not from mosses. This muck he thinks originated in part as vegetable mould which has slidden down into the narrow valleys. It may contain about 30 per cent. of plant material.

Cochrane,[13] who crossed Siberia long ago, was more interested in the people, the roads and the weather than in geology, but he has given some notes respecting localities in eastern Siberia, where his progress was impeded. On the return journey from Nishney Kolymsk, N.L. 69°, E.L. 160°, southwestwardly to Okotsk, N.L. 60°, E.L. 142°, he travelled over a region of mostly overflowed meadows, alder country and "marshy swamps"; the last part of the distance, 7 days' journey, is a continuous swamp covered, at times, with fallen trees. Between Okotsk and Yakutsk, N.L. 62°, the route from the Okota River passes for long distances across wooded swamps; for 50 miles east from the Aldan River, the region is a

[12] J. B. Tyrrell, "Crystophenes or Buried Sheets of Ice in the Tundra of Northern America," *Journ. of Geology*, Vol. 12, 1904, pp. 232–236; also letter of August 3, 1915.

[13] J. D. Cochrane, "Narrative of a Pedestrian Journey through Russia and Siberian Tartary," Amer. ed., Phila., 1824, pp. 220, 225, 234, 238, 319, 325, 342.

most dreary, swampy plain, the road being a wooden causeway in the latter half of the distance. Forty miles of swamp were encountered in the 80 miles east from the Lena River. Cochrane thinks that Siberia is an impregnable province, as, owing to the vast extent of the swamps, a few hours of work would render any one of the roads impassable.

Atkinson[14] has given some information respecting western Siberia between Ekatherineburg and Tomsk. In going from Omsk to Kainsk, a distance of about 200 miles, he crossed much swampy area, continuous at one time for 31 miles. There are many lakes south from Kainsk in an area of 150 by 40 miles, all of them surrounded by broad belts of reeds. Morass prevails between the lakes as well as for nearly 100 miles farther southward.

Nordenskiold's[15] references to peat are merely incidental. His studies were along the coast and excursions into the interior were, for the greater part, comparatively short. The plain on the Yalmal peninsula, west from the mouth of the Yenisei, is tundra-like, full of marshes and streams; on Taimur land farther west, the plains are covered with a continuous, very green vegetation, a mixture of grasses and allied plants with mosses and lichens. In the Gyda peninsula, where Schmidt obtained remains of Mammoth in 1866, N.L. 70°, the stratum containing the remains rests on marine clay and is covered with sands alternating with beds of decayed plant material, completely corresponding with peat deposits formed in lakes of the tundra. The description of the Chukch peninsula, in northeast Siberia, is very similar to that given by Cochrane.

Incidental references in a description by the Comité géologique of Russia[16] give some conception of the marsh-covered area on both sides of the Transsiberian railway. The Steppe de Baraba, between the Irtych and the Ob, about 10 degrees of longitude, is described as differing from steppes at the west in that it has many great marshes

[14] T. W. Atkinson, "Oriental and Western Siberia," New York, 1858, pp. 151, 153, 156.

[15] A. E. Nordenskiold, "The Voyage of the Vega," New York, 1882, pp. 154, 253, 309, 422.

[16] "Aperçu des explorations géologiques et minières le long du Transsiberien," Publié par le Comité Géologique de Russie, 1900, pp. 4, 52, 63, 113.

and forests of birch and aspen. Beyond the Ob, the road passes for about 50 miles through a marshy forest of pines and firs, which extends from near Tomsk southward for more than 300 miles almost to the head of the Kia River. In the area west from Lake Baikal, within the drainage area of the Yenisei, there are impassable marshes of vast extent, sometimes forested—the Taiga. This condition exists between the Kau and Oka Rivers and northward to the Angara. Beyond Lake Baikal, broad valleys hold great marshes covered with vegetation throughout and conifers are abundant in such localities. East from the Yablonovy mountains, the Taiga is characteristic of moist area; pines, firs and black birches are the common forms.

True peat is present in localities where the required conditions appear to be wanting. The so-called forest peat has accumulated to a thickness of several feet in many places within the Rocky Mountain region, the material being merely offal from dense forests of giant firs. In northern New England, one often sees the surface in railroad cuts more or less covered with moss-peat, though the rock is a gravelly sand. This is wholly similar to the Rohhumus, seen so commonly on rock surfaces within forests of both Europe and North America. But the needed conditions are here, though not sufficient to encourage rapid growth. The offal from the trees is abundant and retentive of water, while the moss, once saturated, parts very slowly with its moisture.

Extent of Peat Deposits.—As already stated, a peat deposit may cover only a few square feet or it may cover an area of hundreds even thousands of square miles. The subtropical Everglades of Florida embrace not far from 7,000 square miles; the partly living, partly buried peat of Holland, Belgium and north France has nearly as great extent, as shown by Lorié. Russell's exploration of Alaska led him to assert that peat covers not only the vast tundra but also most of the wooded region as well as of the river plains. The buried deposit of the Ganges delta has been found in numerous borings within a space of more than 2,500 square miles. Skertchly has shown that in the Fenland of England the peat is practically continuous throughout 1,800 square miles.[17] Great areas exist on the north

[17] R. M. Harper, "Preliminary Report on Peat Deposits of Florida," 1910; J. Lorié, "Les dunes intérieures, les tourbières basses et les oscillations du

German border some of which are comparable to the English Fenland. In the majority of the cases cited, accumulation occurred on coastal plains, but the great rivers of Alaska, Sumatra, Paraguay, Brazil and other lands flow amid vast plains, which are peat covered in much of their extent.

The total area, within which peat has been accumulating since the Quaternary began, probably exceeds that in which similar deposits accumulated during any prior period of similar duration. That is not to say that contemporaneous deposits were at any time continuous throughout the area; they were not and they are not, any more than brown coal or stone coal was continuous throughout the regions in which rocks of the respective ages are found. One must always bear in mind that the great deposits of peat did not begin at the same time throughout their present extent. It is altogether probable for all, as it is certain for many, that originally they were small separated patches, beginning in favorable localities and becoming united by transgression. This process is not confined to low-lying areas; Lorié[18] has proved its importance in the Hochmoors of Holland. If conditions favoring growth were checked, the individual deposits would remain isolated.

Growing peat offers great resistance to erosion, as is well-known to those who are familiar with conditions on streams which are subject to violent floods. But where the accumulation is on a permeable yielding material, it may be floated off after long continued flooding. A good illustration has been given by Carpenter,[19] who, in describing a ride through the Panama canal, says that on Gatun lake he found floating islands, tropical swamps lifted from their foundations by the rising water, some of them several acres in extent. Other notes by this author may be given here, though

sol," *Arch. Mus. Teyler,* II., Vol. III., 1890, pp. 424–437; I. C. Russell, "Surface Geology of Alaska," *Bull. Geol. Soc. Amer.,* Vol. I., 1890, p. 129; C. Lyell, "Antiquity of Man," 1871, pp. 336, 337; W. T. Blanford, "A Manual of the Geology of India," 1879, p. 400; S. B. J. Skertchly, "The Geology of the Fenland," Mem. Geol. Surv. of Great Britain, 1877.

[18] J. Lorié, "Les hautes tourbières au nord du Rhin," *Arch. Mus. Teyler,* II., Vol. IV., 1893, p. 169.

[19] F. G. Carpenter, "Steaming through the Canal," *Los Angeles Times,* January 10, 1914.

they concern matters to be considered on another page. He was surprised by the abundance of floating and aquatic plants. Already, within the few weeks of the lake's existence, great beds of water lettuce and of water hyacinth had covered much of the surface and were associated with extensive patches of green scum. The water hyacinth had become a pest. The destruction of forests had been rapid; non-water-loving trees were killed by gradual rise of the water-level, but palms showed great power of endurance. Frequently one of the latter is seen with its trunk completely submerged and only the crown of leaves showing above, resembling a bunch of gigantic ferns on the surface.

But when dried by exposure to light and air peat is unstable material. Change in direction of drainage may deprive a considerable area of the needed moisture and growth will be stopped. Unless the surface be invaded by trees, running water will break continuity of the bog and that will be ruptured into "hags," of which Scottish writers have given vivid descriptions. In a moist climate, this process of destruction is slow, as is seen in much of England and Scotland, because peat absorbs moisture and retains it with great tenacity. It may well be that growth may be checked or wholly stopped in one portion of an area while it continues in another, as in the Fenland of England, where peat still grows in one district, though the general climatic change has caused cessation elsewhere. If untoward conditions continue, the peaty cover becomes desiccated and is removed by the wind or other agencies—a fact which is unpleasantly familiar to those who have cultivated drained peat bogs.

Peat-forming Plants.—Peat, being merely vegetable material undergoing chemical change with greater or less exclusion of oxygen, may be the product of any group of plants. The popular belief, based on surface study of bogs in northern Europe, has always been that mosses are the chief source of material for peat; and this no doubt led to the conception that no true peat is to be found within the tropics, since neither *Sphagnum* nor *Hypnum* prospers amid tropical conditions. Yet more than 100 years ago

Alex. Brongniart[20] announced that peats, consisting wholly of leaves, had been observed in Holland and that similar deposits, formed of leaves from resinous trees, occur in the Jura. There are very many peat deposits without *Sphagnum*. It and other mosses occur rarely in the peats of Florida and it seems to be wanting in the Kampar-Siak area of Java. Molengraaff asserts that mosses contribute little to the peats of central Borneo. C. A. Davis has shown that *Sphagnum* is a comparatively late comer into the Michigan peats and that it is still absent at a great proportion of the localities. Even in northern Europe, many observers have made it clear that mosses are only a few of the peat-forming plants; and in the older deposits there are thick benches in which *Sphagnum* is almost or altogether wanting. But mosses are all-important in arctic and sub-arctic deposits of this day, while they are comparatively unimportant in those of the temperate and sub-tropical as well as tropical areas.

Sedges appear to have been the most important peat producers in much of the north temperate zone; but a peat deposit is not the product of any single plant or group of plants, though this is not to deny the existence of such deposits, for they do occur under exceptional conditions. In the southern part of the United States, one finds conifers and deciduous trees making the chief contributions; the condition is evidently the same in central Borneo, where according to Molengraaff, the peat consists almost wholly of remains of trees, and Koorders makes a similar remark respecting Java. Any plant, apparently, may become a peat-maker; the hyacinth, introduced into Florida, where it threatened to ruin the navigable rivers, has become a peat-producer of no little importance. Certain members of the palm family contribute to the peat deposits of Florida and it appears altogether probable that, when the peats of the Amazon, Orinoco and Paraguay have been studied, palms will be found among the most important of the contributing plants.

It is well known that the sedge-association, in advancing from the shore of a lake or pond, is very apt to form a floating mat. One

[20] Alex. Brongniart, "Traité élémentaire de minéralogie," Paris, 1807, T. II., p. 41.

finds this shown in the Sudd of the Upper Nile. Willey[21] speaks of that as the serious obstacle to navigation between Khartoum and Gondokoo. The principal interruption is 25 miles long and within 150 miles there are three others aggregating 60 miles. The growth is very rapid after an unusually high flood in the upper rivers, which brings down much vegetation and sediment; but if the rainy season be short, the growth is checked and the current carries out the young plants, not yet strong enough to resist. The top in the older denser areas is so dry that it can be burned, but the mass is so matted that it must be cut with saws and the pieces dragged away. This Sudd consists mostly of water-papyrus and a bamboo, known as elephant grass, with a convolvulus creeping over all. Besides this *in situ* material is more or less of transported stuff. One would imagine that this last would be in comparatively small proportion on the lower sections as most of it would be stopped by the first raft.

Wright[22] cites Willcox to the effect that the Sudd interferes seriously with the river's flow. It causes division into numerous streams, which lose themselves, north from Lado, N.L. 6°, in the extensive swamps; Willcox suggested that the channel could be opened by dredging and could be kept open by planting willows on the banks, which would enable the strong current to prevent closing. The absence of willows along the banks makes control of the swamps impossible. Wright cites also Lord Cromer, who notes Major Peake's discovery that the Sudd is not simply a tangle of vegetation floating on the water, but is a mass of decayed vegetation, papyrus roots and earth, much like peat in consistence and so compressed by the current that at places elephants can cross it safely. According to Willey, the thickness is only a few feet in the overflowed swampy area but increases abruptly to 15 and 20 feet in the channel. The close resemblance to the floating mat of more familiar types of sedges is evident. Were it not for the rapid current underneath, the whole channel would soon be filled by the more or less decayed material from the under side of the mat. But

[21] D. A. Willey, "The Barrage of the Nile," *Nat. Geog. Mag.*, Vol. XXI., 1910, pp. 174, 184.

[22] G. F. Wright, "Scientific Confirmations of Old Testament History," Oberlin, 1906, pp. 74–77.

these currents, even in great flood, are powerless against the mat; the river at some places is diverted into a false channel but at others it passes through a series of shallow lakes.

The groups of higher plants, contributing to production of peat, are for the most part those which prefer a soil containing organic acids formed during decomposition of vegetable matter. Some of them are provided with root modifications, enabling them to grow even when rooted in water-covered peat. Others, the ordinary conifers and deciduous trees of swamp areas, have no such modifications and grow only on the less moist portions. In case the water-level rise permanently so as to prevent aeration of the roots, the trees die; but mere accumulation of peat about the roots is not the direct cause of death, as it is proved abundantly by the existence of mighty trees in the western forests, the intervals between them showing several feet of peaty accumulation, in which young firs and scrubby oaks have grown from the seed. The great *Taxodium* and *Nyssa* are rooted directly in the water-covered peat, but aeration is secured by means of the "knees" and the arched roots which rise above the water surface. Aeration is as necessary to these trees as to the others and they can be drowned quite as easily as the junipers. Lowly forms of plant life make, as a rule, merely incidental contributions to peat, but under certain conditions they may accumulate in mass. Some forms of fresh water algæ are constituents of organic muds in pools or ponds, which so often become the foundation for peat, while occasionally one finds a layer of diatomaceous earth in or over the peat.

Classification of Peat.—The great economic importance of peat in some German states led early to close study of that material in all its phases and, of course, to classification, a differentation of the varieties of peat and of the types of deposits. This work had been done in great part by the diggers before scientific students began, so that in all efforts at classification one finds greater or less use made of the popular terms. Zirkel[23] offered a grouping based on the character of the original materials;

Moostorf, derived from water-loving mosses, chiefly *Sphagnum,*

[23] F. Zirkel, "Lehrbuch der Petrographie," Bonn, 1866, Vol. I., p. 398.

Conferventorf, from free-swimming plants, Confervæ, Naiads, etc.,
Haidetorf, heath-peat from various heaths, largely *Erica tetralix,*
Holztorf, mostly from mouldered stems of trees,
Meertorf, from seaweeds, is of rare occurrence.

No one of these forms, except very rarely, is found as the mass of a bog, but all may be seen in the vertical section of a single deposit, indicating variations in conditions during growth. Zirkel gives also the ordinary terms designating difference in composition or structure;

Pechtorf is pitch black to brownish black and is apparently almost homogeneous; the plant remains are so changed as to be practically unrecognizable and the material, when dried, is very similar to Tertiary Pechkohle.

Rasentorf is yellowish brown or wood-brown and the remains of plants are distinct.

Fasertorf designates fibrous remains of plants, penetrating the Pechtorf.

Papiertorf is wood- or soot-brown, with the remains of plants little changed and in separable layers.

Torferde is a peaty earthy substance, friable and with few recognizable plant remains.

Baggertorf is a black-brown, pulp-like peat, obtained by dredging; it dries to a hard mass showing no vegetable structure.

Vitrioltorf contains much ferrous sulphate.

Some of these terms are unimportant, but others are of wide application, designating types which have been considered in all discussions. Von Gümbel[24] introduced a number of new terms, several of which have come into general use. For Pechtorf, he prefers Torfpechkohle, which is the Dopplerit of Haidinger; instead of Baggertorf, he suggests Specktorf and for Papiertorf, Blättertorf. For Fasertorf he would substitute Torffaserkohle; the former term is employed by several writers as descriptive of the felted mass of peat so that it is not definitive. The Conferventorf of Zirkel is

[24] C. W. v. Gümbel, "Beiträge zur Kenntniss der Texturverhältnisse der Mineralkohlen," *Sitz. d. k. Bayer. Akad. d. Wiss.*, 1883, pp. 128–134.

clearly the Dy-gyttja of H. von Post, the Lebertorf of Caspary, the Sapropel-mud of Potonié.

The salient characteristics of peat deposits are practically the same in all lands and the descriptive terms employed in different languages are almost equivalents; the German Hochmoor may be regarded as the Heathermoor of Scotland, the tourbière haute of Holland and France; the Niedermoor, Rasenmoor, Wiesenmoor and Grünlandmoor are but phases of the bogmeadows, morasses and tourbières basses of other lands; and the Waldmoor is a forested bog. Danish students long ago recognized the types under the names of Lyngmose, Svampmose or Hoermose, for the Hochmoor; Kjaermose or Engmose for the bogmeadows; and Skovmose for the wooded bog. Later German writers in some instances use Hochmoor, Flachmoor and Zwischenmoor. These several types, where the succession is normal, occur in definite relation to each other, marking successive stages in the growth of a deposit.

Growth of Peat Deposits.—The succession of stages in growth of a peat bog was determined in detail more than 100 years ago. All who have visited ponds in process of filling by peat are familiar with the ofttimes concentric bands of differing plant associations around the central water-area. This striking feature was emphasized by observers at a very early date, but a comparatively recent reassertion of the relation, as bearing on the formation of coal beds, seems to have come as a revelation to some, who had already discussed various questions relating to coal and coal beds. It is at least strange that the literature respecting peat appears to be unknown to so many geologists, since it is not confined to brief notes or to memoirs scattered through publications of learned societies, but includes elaborate treatises, some of them more than 100 years old. Many of these appear to be inaccessible in this country, but they have been cited so frequently by writers in Europe that one must believe them readily accessible there. Their existence has been ignored in discussion of coal relations, except where a casual reference enables a writer to show that the credit for an independent discovery does not belong to some later investigator. The facts

concerning growth of peat in water-basins have been known long time and the reports of observations were published widely.

In 1839, Palliardi[25] of Franzensbrunn, Bohemia, described a peat bog near that city, which had been dug for fuel during many years. It covers a space of one by three miles and is from 4 to 5 feet thick, occasionally reaching a maximum of 14 feet. The peat grows again in spaces whence it has been removed. In the second year, algæ appear and in the third there is a more definite vegetation, duck-weed being prominent. During the fourth and fifth years, rushes, sedges and reeds form a floating cover, which the natives term the "cow paunch." Within ten to twelve years the surface is covered with *Erica, Vaccinum, Salix* and *Pinus;* and after thirty to forty years the peat may be cut again, if the water-supply have been constant and the cattle kept off. The deeper the deposit, the denser, more like brown coal and richer in bitumen the peat becomes.

In 1854, Vogt[26] recognized that the first stage is apt to be marked by accumulation of aquatic animals and plants, the latter mostly free algæ. Somewhat later, Heer[27] described the process in detail. In water, organic life begins with the algæ; even pure water, exposed to light and air, is full of little plants with boundless capacity for increase; they quickly appear in vast multitudes, which eventually sink to the bottom and, mingled with newer, higher forms, give a layer of organic matter. Then follow the floating mosses in great lawns with myriads of seeds, which, in spite of their minuteness, in time form a considerable mass of organic substance. Thus the way is prepared for life conditions of flowering plants, which arrive quickly. Bladderworts appear and the water-milfoils root in the soil; water-lilies spread out their leaves and cover the water; reeds press out from the shore; rushes and sedges form a thick complex of roots, which gradually extends over the whole and the water is concealed. This peat mass, constantly growing denser, draws moisture from below and in its soft, damp polster nest *Menyanthus, Andromeda* and

[25] Palliardi, in W. A. Lampadius, "Ueber den Schwartztorf und dessen chemische Eigenschaften," *Journ. f. pr. Chem.*, 1839, 2te Bd., pp. 16–18.

[26] C. Vogt, "Lehrbuch der Geologie," 2te Aufl., 1854, Bd. II., pp. 107, 108.

[27] O. Heer, "Die Schieferkohle von Utznach und Dürnten," Zurich, 1858, pp. 2–5.

heaths, which develop the peat foundation. The lake closed, forest vegetation, birch and fir, advances; the firs do not grow high, but they break off after attaining a certain height and weight, sinking into the soft material, where they are converted into peat, as is the less imposing vegetation. They are readily overturned by the wind, so that peat is crowded with birch and firs. Peat originates partly from mosses, partly from water-plants, partly from swamp-plants, especially the grasses and rushes; partly from woody plants. The hard parts change slowly while the softer parts become a pulpy mass enveloping the others. By climatic changes a Waldmoor may be converted into a Torfmoor and that again into a Waldmoor, giving a section in which a succession of forests is shown.

Three years later, von Post[28] grouped the successive deposits into mud (Gyttja), mud-peat (dytorf) and peat (torf), his conclusions being the outcome of more than 20 years' experience in the peat industry. In 1893, he presented a resumé of his studies as a lecture before the Upsala Institute. He had found that most of the Swedish peat mosses began in water-basins and that the bottom material, clay, mud or calcareous tufa, is sediment from more or less muddy water. A most important stratum is the brown earth, Dy in Swedish, which was formed by precipitation from the brown waters, containing huminic substances, quite analogous to the brown waters of rivers. These huminic substances, leached from accumulations on the land surface, are carried into the lakes by heavy rains. Spring water usually contains salts of calcium, iron and aluminum. When this enters the lake, huminic salts of slight solubility are precipitated, giving the brown layers, the Dy or Dy-jord. As this material goes down, it carries with it algæ (diatoms, etc.), fragments of mollusks, water insects and other débris, including excrement of animals. The passage to ordinary peat is gradual. Dy may be forming in the open portion of a lake while successive stages of bog-development are shown on the shores—and it may re-appear within the peat. Overflow, giving a constant rise of the water-level, may cause destruc-

[28] H. von Post, in *K. Vet. Akad. Handl.* (4), 1861, not seen by the writer; "The Formation of Peat-mosses with Especial Reference to the Theories of A. Blytt," *Bull. Geol. Inst. Univ. Upsala,* Vol. I., 1894, pp. 284–288.

tion of trees on a forested moor and bring about return of the peat moss condition.

Pokorny,[29] after exhaustive study of the Hungarian moors, presented a classification of the deposits and described the stages of growth. He recognized two general types, Hochmoors and Flachmoors, equivalent to the supra-aquatic and infra-aquatic of Lesquereux. The former include both forested and *Sphagnum* moors and are confined to higher land, while the Flachmoors, of many sorts and with many names, are on lower land and have an approximately level surface, contrasting with the convex surface of Hochmoors. The successive stages in growth of the Flachmoor are Hydrophyton, Rohrwald, Rohrwiese, Wiesen, Moorwiese, which correspond to those indicated by observers already cited. It is not necessary to make citations from the works by Rennie, Steenstrup, Senft or others of the earlier investigators in northern Europe, for their conclusions differ in wholly unimportant details from those of the later students. It is certain that the successive stages in development of a peat deposit were recognized more than three fourths of a century ago; since that time, the scheme has been modified only in detail.

In 1910, Potonié, using the Memel delta moor as the illustration, summarized the stages thus, in descending order:

Hochmoor,	Sea-climate Hochmoor, Hochmoor Vorzone, in part with *Arundo phragmites,*
Zwischenmoor,	Conifer inner forest zone, Birch zone,
Flachmoor,	Alder moors, Reeds and rushes, shore zone,
Sapropel deposits.	

In a Hochmoor under a land climate, where the rainfall is less, the succession is completed by a heath stage, during which plants of the heath family take possession of the surface. This, Potonié suggests, may be regarded as the expiring stage of peat growth. If a boring were made through the Hochmoor and underlying materials

[29] A. Pokorny, "Untersuchungen über die Torfmoores Ungarns," *Sitz. Akad. Wiss. Wien,* Bd. XLIII., Abt. I., 1861, pp. 59–65, 86.

to the mineral floor, it would pass through beds of the several stages, each of which would be crossed in following the surface from the Hochmoor to the water's edge.

But one must always bear in mind that the order as given is not absolute; it is merely that observed where the filling of a basin has been continuous and undisturbed; any one or most of the stages may be omitted and any stage may be repeated. Local conditions control the succession. That in Michigan, as ascertained by Davis, is, ascending, (1) A deposit formed by *Chara* and floating algæ; (2) in the shallower water, *Potamogeton* followed by water-lilies; (3) next behind is the floating mat of sedges extending to a considerable distance from the shore; material from the under side of this mat accumulates near the shore and (4) shrubs and *Sphagnum* appear; (5) tamarack and spruce advance with ferns.

These stages are distinct around the open water and the trees are all rooted in the peat, which continues to accumulate while the trees are growing. *Sphagnum* is seen first after the surface rises to 2 inches above the water-level.

This general succession is that observed in peat deposits formed within gradually shallowing water-basins; it applies only locally to the great deposits formed on extensive plains.

The Lebertorf or Sapropel Stage.—Klaproth[30] appears to be the first describer of the material known in later time as Lebertorf. In 1807, he reported the chemical composition of a new combustible "fossil," which came from near Bartenstein in East Prussia. The detailed description of the substance leaves no room for doubt as to its relations. No later notice has been seen by the writer prior to those by Steenstrup and von Post.[31] The former recognized a deposit of amorphous material which rests on the underclay of bogs, while the latter described the Dytorf, which usually underlies the peat. The substance was rediscovered by Caspary[32] in 1870. He

[30] M. H. Klaproth, "Beiträge zur chemischen Kenntniss der Mineralkörper," Vol. IV., 1807, pp. 378, 379.

[31] Streenstrup, summarized by Morlot, trans. in *Ann. Rep. Smithson. Inst.*, 1861, pp. 304 ff.; H. von Post in Swedish Academy, 1861.

[32] R. Caspary, "Lebertorf von Purpesseln," *Schrift. k. phys.-ökon. Ges Königsberg,* 11ter. Jahrg. 1870, Sitz., pp. 22, 23.

had received from Purpesseln near Gumbinnen in East Prussia a peat, so peculiar that he visited the locality to learn its mode of occurrence. The moor was of moderate size and shaped like the figure 8, the broad portions being joined by a narrow strip. In the northern division, under a cover of one foot, he found Wiesentorf, 9 feet thick, black-brown and excellent fuel, containing many hard roots and fragments of stems. This overlies 5 feet of "Lebertorf," which is almost homogeneous, green-brown, very elastic, with coarse conchoidal fracture, with no trace of leaf structure and in appearance almost like animal liver. Occasionally, a root fragment occurs. The substance can be ground to powder under water.

When dried, Lebertorf is wholly different. It is grayish-black and almost invariably laminated, but the laminæ are irregular, with no great extent, often as thin as paper and at times in meshes. It parts very slowly with its water; dried by exposure to the air, it is hard and, when cut with a knife, has brilliant black surface like jet. Under the microscope, fresh Lebertorf is found to consist of minute, light, grayish-brown granules with no trace of structure; bits of crustacean tests and well-preserved pollen of *Pinus sylvestris* are abundant; with them are occasional disintegrated parts of plants, showing cell structure. The southern portion of the moor seems to have only an insignificant trace of Lebertorf, the ordinary peat resting directly on the impermeable blue marly clay.

In 1883, von Gümbel[33] examined Lebertorf from Purpesseln and discovered that it has a felted structure. It contains some insect remains, leaves of grasses and mosses, many round balls, probably spores, and vast quantities of pollen grains, more than 1,000 to the cubic millimeter. Specimens from Kimmersdorf, near Gesterode, and from Doliewen, about 100 miles east from Königsberg, agree in that the cross section shows a uniformly dense mass composed of dull material like Boghead. The laminæ are exceedingly thin and contain clear yellow particles and lens-like segregations of red-brown tint along with several thousand pollen grains to the cubic centimeter. He was impressed by the extraordinary resemblance to cannel and conceived that both substances originated in the same way.

[33] C. W. v. Gumbel, "Beiträge," etc., pp. 132, 133.

Früh[34] remarks that algæ are rare and merely accessory constituents of peat, but in some cases they are essential constituents. Material sent to him by F. E. Geinitz from the bottom layer of a moor at Gustrow was, when dry, hard, brown, homogeneous, with a greasy luster on the cut surface. It is laminated, consists in great part of well-preserved Chroocóccaceæ with colonies of other forms of algæ, accompanied by pollen of conifers and *Corylus* as well as by chitinous fragments. He examined Lebertorf from Jakabau, received from Caspary, in which he found pollen and indeterminate remains of higher plants, embedded in a mass composed chiefly of algæ—Chroococcaceæ, Hydrodictyæ and diatoms. Lebertorf from Doliewen, received from Jentzsch of Königsberg, resembles the peat-shale or Torfschiefer from Gustrow and contains, along with pollen of *Corylus* and conifers, well-recognized colonies of *Macrocystis* as chief constituents. The Purpesseln material is similar in composition. Typical Lebertorf has been found at several places in Switzerland, where as elsewhere it consists chiefly of algæ, belonging to genera which are gelatinous. Diatomtorf belongs in this group; he had a specimen from Oldenburg containing 90 per cent. of diatoms.

Jentzsch[35] states that the Lebertorf of Caspary occurs at many places in Germany. Caspary recognized that it has a granular structure; v. Gümbel regarded the granules as exceedingly disintegrated plant remains, while Früh believed them to be algæ. Früh had examined a dried specimen from Doliewen. Jentzsch procured fresh material from that locality and sent it to him. Jentzsch and Caspary could find no evidence that Chroococcaceæ are present in this substance, structureless granules alone were recognized. All Lebertorfs show as chief constituents these roundish granules, which Caspary, v. Gümbel and Jentzsch regard merely as disintegrated plant material; associated with these are pollen from *Pinus* and catkins, bits of plant tissue, remains of crustaceans and often, but not always, diatoms and *Pediastrum*.

In a note appended to this paper, he gives the substance of a letter received from Früh respecting study of the fresh material

[34] J. J. Früh, "Ueber Torf und Dopplerit," Trogen, 1883, pp. 20–24.

[35] A. Jentzsch, "Mikrostruktur des Torfs," *Schrift. k. ph.-ökon. Ges. Königsberg,* Jahrg. 24, 1883, pp. 47–53.

from Doliewen. This had convinced Früh that the micrococcus-forms are not all Chroococcaceæ. He is certain, at all events, that Lebertorf is not genetically an algæ peat; the algæ are only accessory; pollen plays the chief rôle.

The elaborate microscopical examination of oil shales by Bertrand and Renault after 1890 led them to look upon those shales as accumulations of algæ and remains of other types carried down during precipitation of organic salts—an explanation very similar to that suggested by H. v. Post. These studies recalled similar studies of coal by Reinsch and led to farther study of Lebertorf. Potonié[36] made examinations in many localities, which he discussed at various times, publishing his final conclusions in 1910. The Lebertorf of Caspary, Faulschamm and plankton deposit of authors, is termed sapropellite by him. It contains diatoms, *Pediastrum* and other forms of algæ with pollen of *Pinus, Corylus, Alnus* and *Betula* along with remains of various aquatic animals. It accumulates rapidly in enclosed basins and it has rendered some German lakes so shallow that they are no longer navigable. Jeffrey[37] has observed that the bottom of lakes and ponds becomes covered with vegetable matter swept in by breezes or washed in by rains. This is finer in the deeper, less disturbed portions, but coarser in the shallower parts. In one of his figures, showing the finer type, one finds excrement of fish, snails or amphibia, mingled with pollen of conifers. In the other, showing the coarser material, there are merely remains of roots, leaves and other vegetable "flotsam and jetsam." It is noteworthy that he has found no trace of algæ in the lacustrine muck examined by him. Pollen grains and spores are the most important constituents.

The composition of Lebertorf is variable, certain constituents being more abundant at some localities than at others; but of all the constituents, pollen appears to be the most important; other remains are to be regarded almost as accessory, though always present.

Lebertorf cannot be recognized at all localities. Not infrequently it is absent in the lake deposits of north Germany as also in many of those in Sweden and Switzerland. Undoubtedly, the plankton

[36] H. Potonié, "Enstehung," etc., pp. 19–22.

[37] E. C. Jeffrey, "On the Composition and Qualities of Coal," *Econ. Geol.*, Vol. IX., 1914, p. 733, Figs. 151, 152.

conditions existed, but other growth seems to have been far in excess. Sapropelic deposits, as foundation for ordinary peat, appear to be practically wanting in the United States, as no reference is found in publications by Shaler and Harper, while Davis[38] observed them in only three of the many bogs examined by him in Michigan. The most noteworthy of these is that of the Algal lake; but the forms in that deposit are no longer thought to be algæ, their relations being still undetermined.

Lebertorf conditions may reappear at almost any time during the history of a peat bog. Sernander[39] long ago observed the lens-like structure characterizing portions of moors in Sweden, and Weber had called attention to the same feature in northern Germany. The study of peat deposits in Narke by the Geological Commission led to discovery of the causes and the results were published in 1905. The prevailing opinion had been that shoots of the sphagnum-carpet grow uninterruptedly upward, while the under parts die and are converted into peat. But the sphagnum-tips are killed very easily. On portions of the carpet, where such destruction has taken place, growth ceases, while the surrounding moss continues to grow, so that a depression results. Such depressions are very numerous and are due to various causes. One type, frequently observed in Heath- and Waldmoors, is caused by accumulation of offal from the plants; another is caused by surface growth of liverworts or certain forms of algæ; while a third comes from fires, footsteps or other accidents. As the surrounding *Sphagnum* continues to grow, the depressed spots become filled with water; plants growing on the surface are killed and a Dy-like deposit covers the bottom. The ordinary process of filling follows, sphagnum invades the pool and eventually fills it. The depressions sometimes increase by transgression and attain considerable size. An illustrative section, given by Sernander on his Plate 3, shows that interruptions of this kind are of frequent occurrence. Similar depressions are familiar in bogs of all sorts.

In many cases, especially where the water is calcareous, this

[38] C. A. Davis, "Peat," pp. 203, 247, 267.

[39] R. Sernander, "Guide to Excursions," *Cong. Geol. Int.*, XI., Excursion A7, p. 25.

plankton deposit of bacteria, algæ and especially pollen and spores is concealed in the accumulation of marl from *Chara* and mollusks. At best, it is characteristic only of filled water-basins; it occurs rarely in the great deposits originating on broad coastal or river plains. This is not to assert the total absence of such material. Those great deposits frequently were due to union of numerous smaller ones, each of which filled a depression of moderate extent and afterward expanded by transgression on the plain. Lebertorf may form the floor in the original depressions, though it may be thin, owing to rapid invasion by the plants giving normal peat. In the other condition, where swamps were caused by obstructed drainage, Lebertorf-forming agencies no doubt existed, but they did not predominate. Indeed, those agencies are always present, except during periods of interrupted growth, due to dryness, as one may learn by descriptions of almost all bogs, which show that freshwater algæ along with pollen and spores are accessory constituents at all horizons. Whenever a pond is formed in any considerable deposit, such as Dismal Swamp, originally covering not less than 1,500 square miles, the conditions are prepared for formation of a Lebertorf lens.

The Succeeding Stages Vary.—The earlier studies were made almost wholly upon peat deposits filling former water-basins, which had escaped covering and which had had a, so to say, continuous history from a very early period. When the process of filling was uninterrupted save by variations in temperature or moisture, the normal succession may be shown by the bogs in a great area, as in most of Sweden, north Germany and the British Isles. But where the origin was different, a wholly dissimilar section may be found. Geikie, in describing the moors of Scotland, says that they often mark the sites of lakes and ponds, but at times they cover the ruins of ancient forests. When the forest was overthrown, drainage was intercepted, stagnant swamps were formed and water-mosses took root. He refers to several illustrative instances. In the Forest of Mar, large trunks of Scotch fir, which fell from age and decay, were soon immured in peat, formed partly from decay of their perishing leaves and branches and partly from the growth of *Sphagnum* and

other marsh plants. On Loch Brown, the peat cover was completed over the site of a decayed forest in less than 50 years. In 1756, the Wood of Drumlanrig was blown down and experienced a similar fate.[40]

Miller[41] has cited the Earl of Cromarty's description of peat growth in central Ross-shire. When very young, the earl had observed a wood of very ancient trees, doddered and mossgrown, evidently passing through the last stages of decay. Many years later, he passed through the same district and found that the wood had disappeared, while the heathy hollow was occupied by a green stagnant morass. In his old age, he revisited the locality; the surface was irregular and pitted, for the highlanders were digging peat in a stratum several feet deep. The aged forest had been replaced with an extensive peat moss.

The sphagnum-stage is not rarely the first. Dachnowski[42] found *Sphagnum* growing in Ohio on wet sand, where it formed tussocks often more than 4 feet high. This matter will be considered in another connection.

It may be well to note, parenthetically, some other observations by Dachnowski. Davis had recognized in Michigan that *Sphagnum* is indifferent to calcareous salts, growing as well where the water is hard as where it is soft. In Ohio, the nature and quantity of the mineral salts seem to be unimportant, since the heath-sphagnum meadows are abundant in counties where they rest on limestone, while in one locality *Sphagnum* grows in profusion near springs charged with calcium carbonate; this plant in Ohio as in Michigan is indifferent to that salt, for Dachnowski found it abundant in one locality and wanting at another, the conditions being the same in both. Deficiency in mineral matter does not prevent growth of trees on peat; they grow well on the floating mat of heath-sphagnum and in places where the peat is 30 feet thick. In Ohio, the heath-association does not mark the final stage, for it is followed by the bog shrubs. The final stage is marked by the bog-forest association,

[40] A. Geikie, "The Scenery of Scotland," 2d ed., London, 1887, pp. 388–392.

[41] H. Miller, "The Old Red Sandstone," Boston, 1860, p. 174.

[42] A. Dachnowski, "Peat Deposits of Ohio," Geol. Surv. Ohio, Bull. 16, 1912, pp. 224–256.

of which tamarack (*Larix laricina*) and arbor vitæ (*Thuja occidentalis*) are among the first to invade the surface. When bog conditions have disappeared and the surface has become covered with mould, deciduous trees advance and crowd out the conifers. As the mould-cover is very thin and the wet peat is reached very quickly, the roots of this forest group rarely extend downward more than a foot, but they spread out in all directions, as do those of the conifers, thus giving stability.

Structure and Constituents of Peat Deposits.—An intimate examination of a peat deposit leads to conviction that the process of accumulation may not be so simple as is indicated in the preceding generalized paragraphs. There are many modifying conditions.

A peat bog shows, speaking generally, a thin layer of living plants on top, under which the vegetable matter becomes more and more disintegrated downward until, toward the bottom, the greatest part shows no vegetable structure to the unaided eye and the mass consists of felted stuff cemented by a humus-like substance. This cement is removable easily by weak solution of caustic potash and the dried residue tends to fall to a powder. The change downward is not, however, always in increasing ratio.

A peat deposit is rarely continuous from bottom to top, but is commonly divided at irregular distances by partings of one sort or another. These may be thin, consisting of finely divided mineral matter holding a charcoal-like substance, Torffaserkohle of v. Gümbel, or they may be thicker and composed of sand, clay or other transported matter. The thickness of individual partings varies greatly, so that the intervals between the several benches of the deposit may increase or decrease. Lorié's[43] observations in Holland, Belgium and north France make this variation sufficiently evident. The benches themselves differ in peculiarities of the peat and in character of the ash, as one would suppose in view of the different plant-associations marking the several stages of growth.

The opinion has been expressed that a layer of organic material is essential as prerequisite to formation of a peat deposit, and the assertion has been made that, in any event, a Hochmoor with its

[43] J. Lorié, "Les dunes intérieures," etc., *Arch. Mus. Teyler*, II., Vol. III., pp. 424–427, 444.

mosses cannot begin on inorganic material. This material can hardly be determined satisfactorily either positively or negatively, as the thickness of the organic layer is regarded as immaterial, one author holding that it may be so thin as to be unrecognizable, while he still insists that it must be present. There can be no doubt that, when a Hochmoor increases by transgression, it is likely to rest in part upon inorganic material. Rohhumus on bare rock, the sphagnum-peat described by Dachnowski and some instances to be noticed on a later page appear to indicate that a moss peat may begin on inorganic surfaces. At the same time, it is beyond all question that, of deposits originating on the surface of plains, a very considerable proportion began on forested areas, where the litter afforded excellent base for peat growth after the drainage had been impeded. Shaler, many years ago, referred to transgressing bogs in New England, which invaded forests and eventually killed even the water-loving trees. Lewis[44] says that in the lowland mosses of Wigtonshire, Scotland, the till surrounding the original area of obstructed drainage carried birch and *Calluna,* which were replaced gradually by hazel and alder. In these deposits, *Betula* is abundant even on the floor. Sanford regards the Everglades of Florida as due chiefly to impeded drainage. Peat operators have long known that if the bog be stripped clean to the underclay, peat growth begins very much more slowly than when a thin cover of vegetable matter has been left on the clay.

The partings in peat deposits, when consisting of clay, sand or marl, indicate subsidence or flooding. They may be so numerous as to render the mass worthless, the laminations of peat and foreign matter being alike thin; or there may be alternations of fairly clean peat with layers of intimately mingled organic and inorganic materials. The former indicate very frequent floodings, while the latter tell of a long period of subsidence interrupted by longer or shorter periods of comparative stability. A good illustration of the latter condition is that given by Debray[45] in his description of a

[44] F. J. Lewis, "The Plant Remains in the Scottish Peat Mosses," Pt. I., *Trans. Roy. Soc. Edinb.,* Vol. XLI., 1906, pp. 699–722.

[45] L. Debray, "Étude géologique et archéologique de quelques tourbières

section in the valley of the Somme. The deposit is 8 feet thick in 13 wholly distinct benches, varying in thickness from one third to one meter. Four benches, aggregating 2 meters, are of excellent peat, but the others are, in several cases, little better than carbonaceous shale; the ash is calcareous. Similar illustrations are to be found in the American treatises.

In areas where floodings of muddy water are wanting and where climatal variations show little change from year to year, there may be no benches and the mass may be continuous from bottom to top. Johnson[46] has described a peat deposit, which shows about 15 feet of sphagnum-peat, practically continuous. Cook,[47] in discussing the bogs of New Jersey, states that the peat is so crowded with logs of *Chamæcyparis* that one has difficulty in thrusting a sounding rod to the bottom. The condition is the same throughout, even where the peat is 13 feet thick; the Waldmoor growth was uninterrupted. A similar story is told by the cypress swamps. R. M. Harper and others have shown that, in the cypress swamps of Florida, the peat is so filled with logs and woody roots as to be without commercial value. Lyell's[48] statements respecting the cypress swamps of the Mississippi region are in similar terms; for he says that the contractor, in excavating for foundations of the New Orleans gas works, soon discovered that he had to deal not with silt but with buried timber; the diggers were replaced with expert axemen. The cypress and other trees were "superimposed one upon the other, in an upright position, with their roots as they grew." The State Surveyor reported that, in digging the great canal from Lake Ponchartrain, a cypress swamp was cut, which had filled gradually, "for three tiers of stumps in the nine feet, some of them very old, ranged one above the other; and some of the stumps must have rotted away to the level of the ground in the swamp before the upper ones grew over them." It should be said that the whole

du litoral Flamand et du Département de la Somme," *Mem. Soc. Sci. Lille*, Vol. XI., 1872, pp. 471, 472, 475–478.

[46] D. W. Johnson, "The Shoreline of Cascumpeque Harbor, Prince Edward Island," *Geogr. Journ.*, 1913, pp. 152–164.

[47] G. H. Cook, "Geology of New Jersey," 1868, pp. 301, 355, 360, 484.

[48] C. Lyell, "Second Visit to the United States of North America," London, 1850, Vol. II., pp. 136, 137.

delta region of the Mississippi is subject to frequent floodings, but, in a great part of the area, the dense "cane brakes" act as filters, so that the water is freed from its load of silt and continuity of swamp growth is uninterrupted.

There are serious interruptions in the growth, which are not due to flooding or to merely local variations in the water-level but rather to widespread changes in conditions. Benches in thick deposits frequently appear to represent cycles of deposition and these often are separated by thin partings of exceedingly fine mineral matter, containing more or less of fibrous material resembling the mineral charcoal of ordinary coal. Such partings were explained long ago by Lesquereux as due to a period of dryness, when the peat ceased to grow and the surface was destroyed by oxidation to a greater or less extent. The period of exposure may be brief or it may be long continued. A. Geikie and Lewis have made clear that peat forms now in only exceptional localities within Scotland, as the climate has become less moist; and Skertchly asserts that peat is no longer forming in the Fenland of England, save in a dark narrow valley of Suffolk. The peat is wasting in those areas. Similar statements come from other parts of northern Europe. Leaving out of consideration *Taxodium, Nyssa,* certain palms and the trees of the Kampar areas, it is certain that most of the trees growing on peat do not thrive when the material is very wet. Some, it is true, show a notable degree of adaptation. C. A. Davis saw in Michigan a birch in healthy condition, though its roots had been covered with water during more than a year; and there are other types which do well if only the water cover be absent during a considerable part of growing season: the tamarack at times takes root far out on the floating bog, but it grows slowly as do other trees which accompany it. One may learn much respecting changing conditions during the growth of a peat deposit by noting the distribution of trees.

Zincken[49] cites Hartig as saying that in the "rothe Bruche" on the Harz there occur in the lowest 5 feet of the 39 to 40 feet thick Hochmoor, firs with stems 18 inches thick. Higher, is a layer with large pines, on which is another with smaller plants of the same

[49] C. Zincken, "Die Physiographie der Braunkohle," Hannover, 1867, p. 38.

genus, while in the next layer the forms are stunted. Both firs and pines are wanting in the upper portion of the mass. Sernander and Kjellmark[50] discovered that in northern Nericke, Sweden, the succession is (1) Living peat; (2) sphagnum-peat; (3) bed of stumps and roots; (4) sphagnum-peat, passing downward into peat composed chiefly of *Phragmites* and *Equisetum*. The stump layer has birches with needles and bark of *Picea abies, Pinus sylvestris* with fruits, seeds and leaves of other plants.

In the Harz locality, increasing wetness destroyed the trees; in Nericke, trees advanced when the moisture decreased, only to be destroyed when once more the moisture increased.

According to Poole,[51] the great turbary, known as the South Marsh, is double. The upper part is 7 to 8 feet thick and is worked for use as fuel; the lower portion, of about the same thickness, has on its surface everywhere the stumps and roots of trees, standing as they grew. Woodward states that the peat is composed mostly of sedges, so that it is clear that the restoration of marsh conditions led to destruction of the forest which had grown on the bog surface. Skertchly[52] recognized five successive forests in the peat of Wood fen near Ely. Number 1, at the bottom, is of oak and the trees are rooted in the Kimmeridge Clay; Number 2 is at an average distance of 2 feet above the other and consists of yews and oaks, the lower forest having perished before this began, as roots of Number 2 sometimes rest on stumps of Number 1; at 3 feet higher, are the remains of another forest, all firs, and another is just above that; while immediately below the present surface is still another, resembling the modern trees of the region. There were five successive forests, of which all except the first were rooted in the peat. As Skertchly remarks, it is evident that, while in general the climate of the Fenland may have favored peat making, still there were intervals when peat was formed, if at all, in very limited areas, the other portions being

[50] R. Sernander und K. Kjellmark, "Eine Torfmooruntersuchung aus dem nordlichen Nericke," *Bull. Geol. Inst. Upsala,* Vol. II., 1896, pp. 321, 324.

[51] G. S. Poole, cited by H. B. Woodward, in "Geology of Eastern Somerset," Mem. Geol. Surv. London, 1876, pp. 146, 156.

[52] S. B. J. Skertchly, "The Geology of the Fenland," pp. 130, 151, 165, 168, 169.

invaded by forest. The non-peat-making intervals must have lasted more than 150 years, as appears from the size of the trees. The region is now passing through another dry period and the peat bogs are not increasing. De la Beche[53] has referred to the Drumkelin bog in Donegal, Ireland, as affording a striking illustration of interruption in accumulation of peat. At 16 feet below the surface and resting on 15 feet of peat, a house was reached 12 feet square, 9 feet high and constructed wholly of oak. When the peat had been removed from about the house, a paved pathway was disclosed, leading to a hearthstone covered with ashes. Near the house were stumps of oak trees, which evidently were growing when the house was inhabited. A layer of sand had been spread over the surface before the little building was erected. This pause in growth of the deposit was of sufficiently long duration to permit forest growth and to invite habitation. It was followed by return of swamp conditions, during which 16 feet of peat accumulated.

Geikie[54] has recorded several cases of which only two need be recalled here. At Strathcluony, three tiers of Scotch firs were seen, separated by layers of peat. Several tiers were exposed in a railway cutting across the Big Moss, one of standing firs with branching roots at 6 feet below the surface, a second at 12 and a third at 16 feet below the surface; so that, counting the present surface growth, four forests have grown there since the bog-making began; that is to say, the swamp conditions have been interrupted four times by periods of lessened moisture, the last being the present. The preceding three were succeeded by periods of wetness during which peat-making proceeded vigorously. It must not be supposed that even in the drier periods accumulation of peat ceased wholly. It has been known a long time that the offal of conifers can accumulate as peat. Reinsch[55] says that in the Fichtelgebirge needles of Fichten, Tannen and Föhren are important as peat-making material and that in time they accumulate in such quantity that a quaking bog is the result. One must insist here that the mere accumulation of peaty materials around and

[53] H. T. de la Beche, "The Geological Observer," Amer. ed., 1851, p. 134.

[54] J. Geikie, "The Great Ice Age," 3d ed., London, 1895, pp. 286–293, 303.

[55] H. Reinsch, "Ueber den Torf des Fichtelgebirges," *Journ. f. pr. Chem.*, Bd. XVI., 1839, p. 486.

between the trees was not the direct cause of their destruction; but accumulation in an increasingly moist climate might well contribute indirectly by retention of moisture and thereby bringing about the condition in which proper aeration of the roots could not take place.

Lesquereux, Heer, Geikie, Grand'Eury and others have shown by sections in Britain and central Europe this alternation of swamp and forest conditions, while Steenstrup, Blytt, von Post, Andersson, Sernander and others have made the matter abundantly clear for the Scandinavian areas.[56]

The causes of these alterations have been subject of much discussion, as they are among the most striking features of peat deposits. Andersson[57] maintains that the presence of tree stumps in a bog is not necessarily evidence of actual change in climate; that can be explained by the ability of peat bogs to invade forests and to convert them into swamps, as has been proved by several Swedish observers. But this familiar fact can explain only the presence of trees rooted in the underclay; it does not explain the presence of a forest layer with its roots wholly enclosed in the peat. This indicates invasion of the swamp area by the forest. A change in direction or extent of drainage might answer well as explanation of local appearance of trees, for only a slight lowering of the water-level would suffice. But changes in drainage or the encroachment by swamps, while accounting well for local variations in a swamp, great or small, cannot suffice as explanation of widespread variation appearing almost contemporaneously in immense areas. Some general cause must be sought. Blytt and von Post have presented incontrovertible evidence of alternations in climatal conditions throughout Scandinavia; Lewis has done the same for Scotland as J. Geikie has done for a wide area; while Schreiber,[58] after detailed study within the province of Salzburg, showed that the variations in bog life were associated with climatal changes involving migration of the snowline in the Alpine regions.

[56] See "Formation of Coal Beds, II.," *Proc. Amer. Phil. Soc.*, Vol. L., pp. 604–613.

[57] G. Andersson, "Studier öfver Finlands torfmosser och fossila kvartarflora," Bull. Com. Geol. de Finlande, No. 8, 1898, p. 186.

[58] H. Schreiber, "Vergletscherung und Moorbildung in Salzburg." Separate from *Oester.-Moorzeitschr.*, Staab, 1912, pp. 14, 15.

Preservation of Vegetable Matter in Bogs.—The chemical processes leading to conversion of plant matter into peat do not fall within the scope of the present inquiry, but some features must be considered, though without reference to their causes.

Even a casual examination is enough to convince the observer that these processes do not attack all plants or all portions of a plant equally. Bunbury[59] says that the peat in a great bog was found to be merely a black mud, so decomposed as to show no vegetable structure; but at 15 feet down in this mud there was found a horizontal layer, 2 to 6 inches thick, of compressed, undecayed moss, *Hypnum fluitans,* without admixture of other material. The peat below this layer is like that above it. Skertchly[60] notes a similar case. In the turbary near Ely, the peat is digged to a depth of 4 feet. At the top for about a foot it is chestnut brown and not bedded; this is succeeded by 3 feet of black peat, which is bedded, contains roots of reeds, flags, etc., but in the mass shows vegetable structure obscurely; at the bottom is a layer, almost wholly *Hypnum,* which dries to a yellow tint and preserves the vegetable structure. It is well known that the soft parts of plants disappear quickly to become the pulp, in which the harder parts are embedded and of which they themselves eventually become part.

The bark of trees is resistant, even that of trees whose wood decays rapidly. Darwin[61] remarks that in the valleys of Tierra del Fuego, it was scarcely possible to crawl along, the way being barricaded by great mouldering trunks, which had fallen in every direction. When passing over these natural bridges, one's course was often arrested by sinking knee-deep into the rotten wood; at other times, when attempting to lean against a firm tree, one was startled by finding a mass of decayed matter, ready to fall at the slightest touch. There are few living in the temperate zone who have not been startled in like manner by the crashing of a log on which they had set themselves in the woods. The bark had remained sound

59 C. J. F. Bunbury, "Notice of Some Appearances Observed in Draining a Mere," *Quart. Journ. Geol. Soc.,* Vol. 12, 1856, pp. 355, 356.

60 S. B. J. Skertchly, "Geology of the Fenland," p. 135.

61 C. Darwin, "Journal of Researches," Amer. ed., New York, 1846, Vol. I., p. 302; Vol. II., p. 44.

though the wood was wasting away. The rate of decay is indefinite. Darwin estimated that in the neighborhood of Valdivia in Chili, a stump of 18 inches diameter would be changed into a heap of mould within 30 years; but in Java, Koorders, cited by Potonié, saw much fallen timber, decades old yet still in condition for export. In the northern part of the United States, stumps of maples, elms and spruces, 18 inches to 2 feet or more in diameter, are often sound enough after 25 years of exposure to require blasting for their removal. The wood of oaks and conifers is especially resistant, yet even those may go rapidly. Lesquereux,[62] in referring to the sunken forest of Drummond lake in the Dismal Swamp, says that standing stumps of bald cypress (*Taxodium distichum*) are decaying so that many of them are hollow. Fruits and leaves of trees, falling into the water and drifting, are arrested by the hollows of these trees and fill them almost completely. De la Beche,[63] in discussing the decay of plants, observes that "this kind of decay is still more instructive where upright stems of plants in tropical low grounds, liable to floods, retain their outside portions sufficiently long to have their inside hollows partially or wholly filled with leaves and mud or sand, the whole low ground silting up, so that sands, silt and mud accumulate around these stems, entombing them in upright position, without tops, though their roots retain their original extension." Potonié, in 1895, called attention to the fact that hollow alder stumps in West Prussia swamps, exposed to high water, are filled with sand even to the roots, so that they must be cleaned out before the axe is applied.

Generally speaking, the wood of deciduous trees decays rapidly while that of conifers changes slowly. Lesquereux, on the page preceding that just cited, records that in Denmark, about 20 miles below Copenhagen, there is an extensive grassy plain with one foot of humus as the soil. Underlying that is a bed of peat-like material, 6 feet thick, composed wholly of closely packed, flattened birch bark. This, free from earthy matter, is cut out and dried in long rolls. The woody part of the stems, now nearly fluid or transformed into a very soft yellow mud, is at the bottom of the deposit, whence it is

[62] L. Lesquereux, "Geology of Pennsylvania," 1858, p. 847.
[63] H. T. de la Beche, "Geological Observer," p. 133.

removed in buckets and dried for fuel. Debray[64] found plant remains resembling burnt straw within the peat,—the Torffaserkohle of v. Gümbel, a by no means rare occurrence in peat. Birch bark retains its silvery color; the wood of oak is hard and black, but other woods are soft, yellowish and shrink much in drying. Debray observed in this peat of the Somme valley, some shrubs in an inverted position, which he very properly regards as proof that they did not grow where found. Skertchly[65] reports that the birches of Ruskinton fen are represented only by their papery bark, which retains its silvery luster; the bark of elms is preserved but the wood is rotten like touchwood; wood of oaks, always stained black, is often sound enough to be used for gates and fencing posts, though usually fit only for fuel; but the wood of conifers is little changed, that of yews retains the peculiar brown color, while that of firs is as white and sound as if from living trees and the odor of turpentine is distinct when the wood is cut. The *Chamæcyparis* of the New Jersey peat is so good that much of it can be used in building and in cabinet work; the preservation of oak in bogs of Ireland and Switzerland is familiar to all who have visited those countries.

The wood in peat deposits does not always represent material dead or wasted prior to burial. The logs and stumps in the lower portion may be remains of a forest destroyed by advance of the swamp, but that is not necessarily the case with such remains higher in the peat. Trees growing on the surface of peat are uprooted readily by the wind as they have an unstable soil; if the forest be not too dense, such overturned stems sink into the pulpy mass and the deposit becomes crowded with stems, embedded before decay had set in.

Thus one finds logs, in all stages of decomposition, embedded in pulpy matter, derived largely from the soft parts of plants and holding also the waste of various woods as well as abundant pollen, spores, bacteria, fungi and freshwater algæ.

Effect of Pressure on Peat.—Many years ago Lesquereux asserted that peat has a laminated structure and since his time other observers have referred to laminated peat; but this lamination is not

[64] L. Debray, "Étude Géologique," etc., pp. 445, 449, 450.
[65] "Fenland," pp. 160, 161.

so distinct in ordinary peat as to attract the attention of a casual observer. Under pressure, however, the structure is well-defined.

Spring[66] tested the effect of compression on Holland and Belgian peat, mature but retaining much material showing organic structure. Under pressure of 6,000 atmospheres, this was changed into a black, brilliant block, with all the physical aspect of a coal; the fractured surface, as seen under the glass, was distinctly laminated, while evidence of organic texture had disappeared. Under this pressure, the peat became plastic and ran out into the chinks of the compressor. Thoroughly matured peat, after this compression, does not absorb water and does not return to its original form. von Gümbel[67] subjected spongy sphagnum-peat to a pressure of 6,000 atmospheres, by which it was rendered apparently homogeneous and as hard as pasteboard. A pressure of 20,000 atmospheres increased the density to that of sole leather. In each case, lamination was distinct and the streak was lustrous, but when placed in water, the material swelled to almost the original bulk. Evidently, pressure of brief duration suffices to produce permanent physical change in well-matured peat though not in the immature substance. But one is not dependent on laboratory results; the experiment has been performed in nature many times and on a grand scale.

Forchhammer,[68] in his descriptions of dunes on the Baltic coast, of Denmark, states that among those dunes are numerous lakes and ponds characterized by abundant vegetation and by formation of peat. When an unusual storm passes over the dune, sand is blown into the ponds and puts an end to growth of peat. This buried peat, known as Martörv, is exposed when currents cut away the coast. The phenomenon is not confined to the mainland; on the north side of Seeland, there was a pernicious stretch of quicksand early in the eighteenth century but, before 1760, it had become

[66] W. Spring, "Recherches sur la proprieté que possedent les corps solides de se souder par action de la pression," *Bull. Acad. Roy. Belg.*, II., Vol. 49, 1880, pp. 367, 368.

[67] "Beiträge," etc., pp. 127, 128.

[68] G. Forchhammer, "Geognostische Studien am Meeres-Ufer," *Neues Jahrbuch,* Jahrg. 1841, citations from pp. 13, 14.

watered and covered with a dense forest of fir. On the border of the dune, the sand covered part of a peat-moor, where it had stopped growth while accumulation continued unchecked on the uncovered portion. Peat from the latter does not differ from that of bogs in the neighborhood, but that from the sand-covered portion has been changed into a wholly different substance. Ordinary Moortorf, dried, weighs from 16 to 20 pounds per cubic foot, but that which has been compressed by the dune weighs 78 pounds. In ordinary peat, dried, one finds scarcely any trace of layers, but this compressed peat is almost shale-like in lamination. The Seeland peat is formed mostly of offal from a forest vegetation, but in hand specimens one cannot distinguish it from brown coal.

v. Gümbel in 1883 found that the Martörv has alternating bright and dull laminæ, the bright portions consisting chiefly of ribs and hard parts of grass leaves with admixture of other parts, pollen, etc. He thought that it bears much resemblance to Lebertorf, but it is clearly of different origin. One would surmise from the conditions that this Martörv contains both mature and immature peat. The observations by Jentzsch are confirmatory. He remarks that the Martörv found near Rixhoft in East Prussia is derived without doubt from the Bielawe and other moors, that it is compressed material from underneath the dunes, which now separate those moors. Nilson[69] has described a vast gravel deposit which follows the Baltic coast of Sweden for a long distance beyond Ystad and, at various places, rests on peat.
This material is similar in composition to the recent peat of Sweden.

Lesquereux's[70] description of conditions in the valley of the Locle in Switzerland is equally to the point. On the side of the valley, under a heavy bed of marl, he found 3 inches of compressed material, hard, fragile and with brilliant fracture; lower down the slope, where the marl is but 4 feet thick now, the deposit is 6 to

[69] Nilson, cited by J. Geikie, "Prehistoric Europe," p. 473.

"The peat under this stone wall is so compressed that, when dry, it is almost as hard as brown coal; the trees also are, like the layers of coal, pressed together, and when a fir chip is broken, it is found to be black and shining in the cross-section, all the result of great pressure and age."

[70] L. Lesquereux, "Quelques recherches sur les marais tourbeux," *Mem. Soc. Sci. Nat. Neuchatel,* Vol. III., 1845, pp. 95, 127.

7 inches thick and retains some peat-like features, but is a passage from the lignite of the border to the peat of the open valley, which has been growing continuously, so that it is now 8 feet thick. In another connection, he remarks that some deposits of lignite are surrounded by peat. Goeppert's[71] observation is very similar. A deposit of peat was found in the low part of a valley near Helvetihof in Upper Silesia. On both sides of the valley, a portion of the deposit is covered with 2 to 10 feet of soil and sand beds, under which the peat has been changed into a distinctly laminated, hard black mass, almost like stone coal; whereas the peat in the open valley, uncompressed, has the usual brown color and comparatively loose structure.

Preservation of Peat Deposits.—The surface of a dead bog is often irregular as though it were wasting away; the peat-cover of a drained area, under cultivation, disappears within a few years as ploughing exposes more and more of it to oxidation, drying and the winds. A casual observer of the "hag" region of Scotland feels justified in believing that peat is formed only to decay and that little of it will survive to reach a more advanced stage of transformation. This is the conclusion reached by an eminent student of coal problems and his opinion appears to have been accepted as fact by several authors. But the conclusion cannot be accepted as final; it seems to be based on incomplete observation or on lack of familiarity with conditions in great areas. The process of removal, where man does not interfere, is slow, because peat, with its felted structure and its obstinate retention of water, offers great resistance to erosion. A very thin cover of fresh peat protects itself and the underlying rock from removal. The effect of oxidation is not rapid, as it is necessarily superficial, circulation of air in the drying peat being confined to the newer portion.

Lowering of the water-level does not mean that the surface is to become dry and pulverulent, to be swept away by the wind. In most cases, that lowering of the level leads to invasion by plants which cannot endure wet conditions, to the growth of a rather dense cover of vegetation which, by its accumulating offal, protects the

[71] H. B. Goeppert, "Abhandlung eingesandt als Antwort auf die preisfrage," etc., Amsterdam, 1848, pp. 104, 105.

peat already formed and adds to the mass. As soon as local or general conditions again become favorable, peat growth in the ordinary way would be resumed and the invading vegetation would be killed. The record of alternating wet and dry periods is distinct in very many deposits which offer no evidence of serious waste during the passage from one to the other. Some of the less moist periods must have continued for centuries, if one may judge from the age of rooted trees in the forest layers. Certainly the desiccation process did not extend deeply, for the roots of trees in those layers are spread horizontally in shallow depth, as though avoiding the wet peat below, just as do the roots of the invading forest trees now.

It is wholly possible that comparatively little of the peat now forming will reach a later stage in transformation; the agricultural importance of peaty lands is understood, as is also the method for their preservation, so that the work of drainage and reclamation will be more and more extensive in the future. But with that this study is not concerned. The questions involved deal with conditions prior to man's interference with nature's operations. The evidence all encourages the belief that a very great part of the older peat has been protected and that the peat now forming in uninhabited regions will be protected in like manner, to become a genuinely fossil fuel. Buried peat deposits are known throughout the world.

Forchhammer, Jentzsch, F. E. Geinitz and others have described dune-covered bogs along the Baltic shores and C. A. Davis has referred to the same condition in Michigan. The process continues in those regions. One finds frequent notes respecting submerged bogs, often continuous with living bogs on the shore, as though the swamp had advanced up the surface during the subsidence. In some localities, portions of the submerged bog are already covered with materials from the land, while other portions are still free from cover; in such cases, the overlying deposit should contain marine forms. At times, the influx of inorganic matter continues until land conditions, have been restored and the peat extends over the new surface. Borings in northwestern Europe pass through a succession of peat bogs separated by sand or clay. Similar relations are exposed in deep excavations and occasionally in uplifted areas.

J. Geikie[72] has given numerous instances of submerged deposits on the coast of Scotland. Farther inland, in the Carse lands on both sides of that country, deeply buried deposits have been exposed by the rivers. The River Tay has cut its channel down to a peat bog, now forming the river bed and underlying about 17 feet of alluvial material, which near the top contains cockles, mussels and other marine forms. In some parts of the wide Carse area, this extensive deposit rests on alluvial sands but in others on marine clays. The peat is much compressed and splits readily into laminæ, on whose surfaces are small seeds and wing cases of insects. As a rule, it is marked off sharply from the overlying clay and silt, but, at times, it is covered with vegetable debris which was drifted in from places higher up in the valley. Skertchly[73] found that on the Isle of Ely the peat underlies 4 to 8 feet of silt and clay and rests on clay, both roof and floor being marine, the peat marking an interruption in deposition of the clays. Several peat beds are within 12 feet; the lowest, 18 inches thick, is normal, black and clean; but the higher peats are irregular and impure, mingled with clay, showing the contests between plants and muddy water. Travis[74] has described a case of marine association, which shows also a by no means unusual relation of the beds. The Seaforth Dock excavation, 40 feet deep, 180 wide and 900 long, exposes two beds of peat. The lower, 18 to 24 inches thick, rests on gray sand and is shown for about 280 feet. At 5 to 10 feet higher, the interval being filled with *Strobicularia* clay, is the upper bed, 12 inches thick, which is exposed for 480 feet. It overlaps the lower one, which thins out. The peat in both bands is firm, woody, with occasional fragments of bark and twigs, but it contains no stumps or trunks of trees.

Lorié has recorded a great number of borings in Holland, which illustrate the succession of buried peat beds, separated by sands deposited beneath the sea. Rutot has given records showing peat beds intercalated in marine sediments on the coast of Belgium.

[72] J. Geikie, "The Great Ice Age," 1895, pp. 290–293.

[73] S. B. J. Skertchly, "Fenland," pp. 140–143.

[74] C. B. Travis, "Geological Notes on Recent Dock Excavations at Liverpool and Birkenhead," *Proc. Liv. Geol. Soc.*, Vol. XI., 1913, pp. 237–275.

Sirodot[75] refers to a locality, where one finds a series of alternating peat and marine deposits, which he explains by supposing that a bar was formed and broken repeatedly, so that the enclosed area was alternately freshwater and marine.

But this burial comes also to inland deposits, to those on great deltas or at the heads of long estuaries, where the covering material is of freshwater origin. Much of the Holland-Belgium-France area, in all more than 7,000 square miles, was not under the sea at any time since the peat began to form; the great peat bed of the Ganges delta is at 20 to 50 feet below the somewhat irregular surface and is covered with river silts in an area of not less than 2,500 square miles. Entombment seems to be the fate of large and small alike. Phillips[76] has recorded the section of the Holderness peats, thus: (1) Clay; (2) peat, with plants, trees and roots; (3) variegated clays, with freshwater *Lymnæa;* (4) peat, like No. 2; (5) clay with freshwater Cyclads; (6) bituminous clay; (7) coarse sandy clay. Number 2 is the persistent member of the section, but varies greatly in thickness and character. Near Hull, it is 30 feet below the surface and 2 feet thick, containing large trees, Buried swamps abound on the Atlantic coast of the United States, especially along streams emptying into the long estuaries occupying "drowned valleys." One citation suffices to illustrate the conditions. Berry[77] says that such swamps are exposed by erosion at many places along the James, Rappahannock and Potomac Rivers, all emptying into Chesapeake bay. Most of those observed in 1907–09 were cypress swamps, though some were of the open type with birch, oak, pine and other forms. When quiet conditions accompanied subsidence of the forest bed, clay is the roof, containing *Unio,* if the locality be near the head of the estuary, or *Rangia cuneata,* if farther down within reach of saline water. This condition of quiet subsidence is shown in the photograph of an exposure

[75] Sirodot, "Age du gisement de Mont-Dol," etc., *Comptes Rendus,* Vol. 87, 1878, pp. 267–269.

[76] J. Phillips, "Illustrations of the Geology of Yorkshire," 2d ed., 1835, Vol. I., pp. 25–27.

[77] E. W. Berry, "Pleistocene Swamp Deposits in Virginia," *Amer. Naturalist,* Vol. XLIII., 1909, pp. 432–436.

near Tappahannock, Virginia, where a bed of massive hard peat is exposed for half a mile. This is covered with plastic clay, 1 to 4 feet, underlying 10 to 15 feet of coarse sand. One sees many cypress stumps in place, with their "knees" projecting into the sand. Where the subsidence was accompanied or followed by disturbance, the evidence appears in the more or less planed or eroded surface on which gravel or sands rest, as is shown in a photograph of peat with embedded cypress stumps, which is unconformable by erosion to the overlying sands.

Greater interest attaches to the interglacial buried peats, which have been covered with material transported during the Ice Age. These, underlying clays, sands or gravels, exhibit many features which are important here. Such deposits have been observed in many lands.

The deeply buried peat of Montgomery county, Ohio, originally studied by E. Orton, Sr., has been restudied by Dachnowski.[78] The exposure is in the bank of a tributary to the Miami River and underlies 80 to 100 feet of stratified clay and gravel. There are indications that the deposit is part of a large area and that it marks the deeper portion of an extensive water-basin. The thickness, as now exposed, is from 1 to 4 feet, but, 45 years ago when Orton's description was written, it was from 12 to 20 feet. The uppermost layers contain undecomposed sphagnum-mosses and underlie fine silty blue clay. The lower portions grade into a well-decomposed, very compact peat which holds fragments of wood. This peat rests on several feet of fine sand underlain by clay and gravel. Near the southern margin, according to Orton, a large quantity of timber was found, roots, branches and twigs, much of which had been flattened by pressure. The wood is largely but not exclusively coniferous. Newberry[79] recalled Collett's discovery in much of southern Indiana of a buried deposit, 2 to 20 feet thick, containing rooted stumps. In later years, W J McGee, F. Leverett, F. B. Taylor and J. W. Goldthwait have described interglacial deposits, some of which are very extensive.

[78] A. Dachnowski, "Peat Deposits of Ohio," Geol. Surv. Ohio, Bull. 16, 1912, pp. 102, 103.

[79] J. S. Newberry, "Geological Survey of Ohio," Vol. II., 1874, pp. 30-32.

Dunlop[80] has given details of a section observed by him at about two miles from Airdrie, Scotland. The order, descending, is (1) Alluvium, 3 feet; (2) peat, with trees standing up through it, 2 feet; (3) Upper Boulder clay, containing a 4-inch layer of vivianite near the bottom, 4 feet; (4) sand with partings of fine clay, 11 inches; (5) peat, 1 foot 5 inches; (6) Boulder clay, not measured. The upper peat bed is recent, but the lower is interglacial. The peat of the latter splits readily into layers and darkens somewhat rapidly on exposure. Some layers consist of seeds of *Hippuris vulgaris* and *Menyanthus trifoliata;* others are wholly of mosses and, near the bottom, are some containing abundant remains of beetles. But no traces were found of the trees usually found in bogs, aside from some leaves resembling willow. The cover is sand but silica is practically wanting in the peat, which, air-dried, contains 6 per cent. of ash, mostly oxide of iron. In this bed are boulders of sandstone and gneiss, varying in size and distributed irregularly; all are waterworn and those which are little disintegrated show ice-markings.

Reid's[81] report, on behalf of a committee, which studied the deposits at Hoxne, on the border of Norfolk and Suffolk, England, relates that at that place a bed of lignite, 1 to 3 feet thick and disappearing at the borders of the valley, rests on a carbonaceous clay containing lacustrian shells and some drifted seeds. The bulk of the lignite consists of alder wood preserving the bark, offal from alders along with remains of other plants, all of the swamp-loving type—altogether, 37 species of flowering plants and 11 of mosses. The presence of pools in the swamp is indicated by the occurrence of *Valvata, Pisidium,* rare fishbones and elytra of beetles in the lignite; every plant indicates a temperate climate. A black loam, 13 feet thick, overlies the lignite: it is beautifully laminated and contains well-preserved remains of plants belonging to a cold climate, the arctic willow and birch. Fragments of plants belonging to a temperate climate occur in this loam, but their condition shows that they were derived from the underlying deposit. Above the loam are

80 R. Dunlop, "Note on a Section of Boulder-Clay, containing a Bed of Peat," *Trans. Geol. Soc. Glasgow,* Vol. VIII., pp. 312–324.

81 C. Reid, "The Relation of Paleolithic Man to the Glacial Epoch," *Rep. Brit. Assoc. Adv. Sci.,* 1896, pp. 400–415.

gravels and brick-clay, the latter containing freshwater shells, fragments of wood and paleolithic implements. These facts presented by Reid show that the peat has been converted by pressure into a lignite-like substance; the growth of the swamp was checked and the peat may have been exposed during the considerable period of changing climate, which led to the introduction of a subarctic flora. Direct superposition and conformability are certainly not evidence of continuity of deposition.

De la Harpe[82] saw a bed of peat at Lausanne, Switzerland, one meter and a half thick, underlying gravel and resting on marl. The peat is mixed with marl in the lowest part and the highest part contains some fine micaceous sand. Here and there in the black peat are occasional rock fragments, wholly isolated, as though one had cast them into the soft mass. Seeds, tree stems and branches, altogether decayed, were observed with, here and there in the upper part, a fragment of bark resembling birch. The underlying marl is without pebbles but has abundance of *Lymnæa, Valvata, Planorbis, Cyclas* and *Pisidium*.

Keilhack[83] saw a coal deposit near Lauenberg on the Elbe, with these relations, descending: (1) Upper clay, with shells; (2) diluvial sand, 15 meters; (3) coal bed, consisting of (*a*) fragmentary coal with stems and branches, (*b*) fruits and leaves, (*c*) moss; (4) clay; (5) diluvial sand with *Cardium edule*.

No additional details are given in the abstract. During the discussion, Hauchecorne and Beyrich insisted that the material is not coal but peat. Evidently the change in physical character was sufficient to make the relations somewhat doubtful. It is to be noted that the transformation is most advanced in the upper part and that the moss at the bottom appears to have undergone little change.

The deposits at Klinge, near Kottbus in Brandenburg, have given rise to much discussion as did that at Lauenberg. Keilhack[84] examined the great excavation and observed this succession, descend-

[82] Ph. De la Harpe, "Sur un gisement de tourbe glaciaire," *Bull. Soc. Vaud. Lausanne,* Vol. XIV., 1877, pp. 456–458.

[83] Keilhack, *Zeitsch. d. d. geol. Gesell.,* Bd. XXXVII., 1885, p. 549.

[84] H. Keilhack, "Der Alter der Torflager und ihrer Begleitschichten von Klinge bei Kottbus," *Zeitsch. d. d. geol. Gesell.,* Bd. XLIV., 1892, pp. 369–371.

ing: (1) Diluvial sand, 2 to 2.5 meters; (2) carbonaceous clay, 1.2 meter; (3) brown coal, peat-like, 1 meter to 3 decimeters; (4) clay marl, 3 to 3.5 meters; (5) peat, 45 centimeters; the upper part is Moostorf with seeds and reeds, while the lower portion has leaves, wood, seeds, rhizomes of *Nymphæa;* (6) Lebertorf with diatoms, 1.1 meter.

The Lebertorf is a lens-like deposit and is replaced in the southern part of the excavation by a meter of sand. Keilhack could not determine the age of the beds and maintained that the matter could be determined only by a boring. A. Nehring, in the discussion, held that the deposit is interglacial and probably equivalent in age to the Schieferkohle of Utznach and Dürnten. Credner[85] visited the same locality and obtained a section, evidently from another portion of the excavation. The peat is a single bed with maximum of a meter and a half, Number 4 of Keilhack's section being absent. The Lebertorf rests on clayey marl overlying sand. He thinks that the peat is post-glacial. In the following year, Potonié[86] summed up conclusions presented by H. Credner, H. Keilhack, A. Nehring as well as by other observers and discussed in detail the relations of the flora found in the Klinge deposits. This is distinctly diluvial. The succession is that of so many peat-filled basins, Lebertorf below, succeeded by peat in which are many erect rooted stumps, clearly *in situ.* The compression, due to weight of the overlying deposit, had so changed the appearance that Keilhack thought it brown coal with peat-like features, while Credner preferred to call it peat with resemblance to brown coal.

Weber[87] described two interglacial peat deposits, exposed during excavation of a canal from the Elbe to the Eider. One, seen where the canal emerges upon the Eider lowland, is exposed for more than 1,600 feet. The underlying material varies. The bed is in two divisions separated by sand; the upper one has suffered much from disturbance and is broken up badly, while the lower one is practically

[85] H. Credner, "Ueber die geologische Stellung der Klinger Schichten," *Ber. Ges. Wiss. Leipzig,* Bd. XLIV., 1892, pp. 385–402.

[86] H. Potonié, *Naturwiss.-Wochenschrift.,* Bd. VIII., 1893, pp. 393 ff.

[87] C. Weber, "Ueber zwei Torflager im Bette des Nord-Ostsee-Canales bei Grünenthal," *Neues Jahrbuch,* 1891, Bd. III., pp. 62 ff.

undisturbed, though at one end of the exposure it is curved upward so as almost to reach the surface. The succession in the lower division is clearly that observed in peat-filled ponds. The quartz sand on which the peat rests is without lime; by increase of humic matter, it passes gradually into peat with roots, leaves and fruits of *Potamogeton* and rhizomes of *Phragmites; Hypnum fluitans* appears at the top of this bottom layer, which passes upward into a thin layer of hard peat, mostly *Hypnum fluitans* accompanied by *Potamogeton* and *Phragmites,* the latter increasing above. Indeterminate fragments of beetle-elytra, pollen of conifers and *Betula,* with spores of *Hypnum* are abundant. This in turn passes very gradually into the third layer, 65 centimeters thick, very sandy brittle peat, containing abundance of twigs and roots of *Pinus sylvestris* with leaves, seeds and wood of *Betula verrucosa,* leaves of willow and wood of *Corylus;* there is much compressed wood, probably willow, some wood of fir and juniper was seen along with rhizomes of *Nuphar, Typha, Potamogeton,* etc. The highest layer is moss-peat, about a meter and a half thick, mostly *Hypnum hamifolius* with very little wood and rare *Sphagnum.*

The conditions are similar to those recorded in many recent peat deposits. But during deposition of the overlying sand, as shown by Weber's profile, the lower beds suffered much from erosion at one side, where the upper surface is jagged. The whole mass, including both divisions and the sand parting, has been subjected to severe lateral pressure, producing disruption of the upper division, upturning of both, so that the old peat deposit is almost united to the recent bog covering the present surface.

Molengraaff[88] reports that, in Borneo on the Mandai river, he saw thin layers of peat alternating with clay loam, the peat so compressed as to resemble brown coal. On the same river he saw thin beds of coal, evidently of recent origin; it is of poor quality, is laminated, lustrous, and has cleavage in two directions, breaking into parallelopipedons.

The deposits of Schieferkohle show similar features but on a much more extensive scale. Heer[89] examined the Schieferkohle at

[88] G. A. F. Molengraaff, "Borneo," etc., Eng. ed., p. 43.

[89] O. Heer, "Die Schieferkohle von Utznach und Dürnten," Zurich, 1858,

Dürnten, where he found about 12 feet of coal resting on marly clay, with freshwater mollusks, and underlying about 30 feet of sand and gravel. The bed is divided by six partings of dark earthy material unfit for fuel and, in all, about 2 feet thick. The benches of coal are not alike. The lowest contains much wood and cones of *Pinus abies,* which are wanting in higher parts of the bed. In each of the upper benches, one finds, first, layers of moss felted into dense masses and pierced by reeds, which are followed by trunks lying in all directions, associated with roots, barks and pieces of wood, seldom very thick and always pressed flat. The annual rings are distinct though, at times, they have been distorted by the pressure. Some stems are wholly coaled as if by lightning. The tree trunks, as in peat, are embedded in a brown-black substance, derived unquestionably from herbaceous plants and originally forming a pulpy mass. This succession appears in every bench except the highest, in which reeds and mosses predominate, while stems of trees are comparatively rare. At Unterwetzikon, the lignite rests on marl with freshwater shells. At Utznach, there are two beds of lignite, 5 and 3 feet thick, separated by 16 to 20 feet of marly deposits. At Morschwyl, the Schieferkohle, variable in thickness, overlies and underlies marl and has a cover of 26 to 70 feet. It contains vertical stems, which in many cases extend into the overlying marl.

Heer's study of the plants proved that the resemblance of Schieferkohle to peat is complete. The trees are *Pinus abies, P. sylvestris* and *P. montana,* which are prostrate—they must have been overturned and been sunken in the bog. The wood is soft when first removed, but it hardens quickly on exposure; the bark is commonly present and twigs and branches, retaining the leaves, occur frequently. Other trees are yew, larch, white birch and sycamore. The last is represented by a few leaves in the lignitiferous clays. *Corylus* is not rare; *Menyanthus* is represented by abundant seeds and *Phragmites* abounds in the clay partings with *Scirpus; Sphagnum* and three species of *Hypnum* were obtained at Dürnten. The Schieferkohle and its partings contain abundance of mussels and swamp in-

pp. 7–11; "The Primæval World of Switzerland," London, 1876, Vol. I., pp. 29, 30; Vol. II., 155, 157, 160–163.

sects, while among the higher animals which perished in the bog are *Rhinocerus leptorhinus* and *Elephas antiquus*.

Deicke[90] looks upon the Swiss diluvial coal as a link between peat and brown coal; it passes over into both types. He discussed only the Morschwyl deposit as Heer had given details respecting those at Utznach and Dürnten. The coal lies in diluvium, 40 to 50 feet above the Miocene, is covered with drift-material, often 80 feet thick, and rests on ashen-gray shale or on a clayey sand containing small pebbles. The lowest coal layer encloses very many stems of trees, among which Scotch fir, red and white spruces, oaks, birches and others can be identified. All had been broken off and the fragments are from 8 to 12 feet long with, in some cases, a diameter of 3 feet. Except where the stumps are rooted, the stems are prostrate and show very marked compression. Birches are much flattened, the width of a stem being often 24 times its thickness. Conifers are less compressed, the width being rarely more than 4 times the thickness. Above this layer is a clay-shale parting, one foot thick, on which rests a coal composed chiefly of grasses and mosses, but containing many birches, some Scotch firs and rare spruces. In the clay shale and in the lower coal, Deicke found a great quantity of cones of Scotch fir, red and white spruce, rare cupules of oak, seeds of various grasses and wings of insects. The second bench of coal is succeeded by 4 feet of coaly shale, on which is another coal bed, averaging 3 feet and broken by shaly partings. The whole deposit thins away toward the borders. The coaly shale has nests of Schieferkohle and shows erect stems which, though fractured, are not compressed. Deicke recognizes Waldmoor conditions here; a forest was overwhelmed by mud, on which a Torfmoor developed. The trees died and were blown over; cones of spruce and fir remained in the mud and projected into the growing peat; Scotch firs, birches and the rest grew on the peat and were destroyed, when that material increased. Then came the influx of detritus and the resulting compression. Wood comprises about one tenth of the mass. When exposed to the air and sunshine, the lignite changes, loses texture and becomes Pechkohle; but complete change takes

[90] J. C. Deicke, "Ueber die Diluvial-Kohle bei Morschwyl im Kanton St. Gallen," *Neues Jahrbuch*, 1858, pp. 659–663.

place only in small stems and is rare when the diameter exceeds 2 inches. One end of a stem may be changed while the other retains its woody structure.

Klebs[91] described a coal which he saw at about 30 miles southwest from Königsberg: it underlies 15 feet of sand and overlies gravel, both of them diluvial. The section, descending, is: Black earthy coal, 1 foot; clear brown coal, 7 inches; dark, brown coal, 3 inches. The three benches are as sharply distinct as those of any peat bog or bed of stone coal. The whole thickness, including the thin partings, is 2 feet and the middle bench is harder than that above it.

Von Gümbel,[92] who had studied the Bavarian Schieferkohle in place, subjected to microscopical examination material collected at localities in Bavaria and Switzerland. He describes the Schieferkohle as partly loose, partly dense in structure, often like Pechkohle. It contains many flattened branches and parts of trees belonging to conifers, birch, willow, alder, in part lignite but at times already Pechkohle. Solution of caustic potash converts the less dense portion into a soft closely felted mass, in which the microscope shows, as predominating, parts of mosses and grass leaves. Tissue of wood appears rarely. The dense Pechkohle required treatment with Bleichflussigkeit (potassium chlorate and nitric acid) in order to bring out the structure. The densest material is that from Morschwyl, which shows the same plants as those in the looser or less dense portions along with an amorphous textureless substance like dopplerite. The density is due to this material, which he terms Carbohumin. Pollen, spores of mosses and lichens are not very abundant; cones of conifers are numerous in the coal mass, but are little deformed though they lie alongside of compressed stems. The inside of stems is yellowish and soft like decayed wood, but the bark zone has been converted into bright Pechkohle.

The Bavarian localities are typical. At Imbergtobal, near Sonthofen, a brown coal deposit is divided by partings of sandy marl, which are crowded with plant fragments and conifer needles

91 R. Klebs, "Die Braunkohlenformation um Heiligenbeil," *Schrift. Ges. Königsberg,* Jahrg. 21, 1880, p. 82.

92 C. W. v. Gümbel, "Beiträge," etc., pp. 135–138.

and have the features suggesting deposition by floods, which repeatedly overspread the continuously growing peat. They bear close resemblance to the partings seen in most coal beds. At Grossweil, near the Kochelsee, the Schieferkohle consists of easily separated layers of brown coal, twigs and wood fragments with others of leaves of grasses and mosses. The composition is made clear by solution of caustic potash. *Sphagnum* is the chief constituent of the moss layers; in others, pollen is abundant with small nests of fibrous peat and an alga. The deposit is distinctly one of peat and, at all localities, the coal-like and the peat-like portions pass gradually into each other.

Von Ammon[93] has given some notes respecting the distribution of Bavarian Schieferkohle. He states that a diluvial formation extends along the Loisach in an area of 9 by 2 kilometers between the Murnauer Moos and the Kochelsee. In this is embedded the coal bed mined near Grossweil (about 40 miles south-southwest from München), which he thinks is a forested Flachmoor of intramorainal age. It was opened at one time near Ohlstadt, where it is double and about 1.6 meter thick. At 10 meters above is another bed showing coal, 0.7 and 0.6 meter, separated by a parting of one meter. The coal is an earthy brown coal with inclusion of lignite. The Schieferkohle of Sonthofen varies much but is often several feet thick. At Josephsfelde, the thickness is from one to 3 meters; at Imbergtobal, there are two beds, three meters apart; the lower is from 2 to 5 meters thick and upper about 1.5 meter and impure.

Schieferkohle occurs in extensive deposits within Upper Austria, Styria and Tyrol. Lorenz[94] reported upon the conditions observed by him in the Hausrucker mountains of Upper Austria. The succession is: Fragmentary material, Kohle-Tegel system, Tegel, and the deposits appear to be conformable. The coal-marl system is from 100 to 150 feet thick and at most localities it shows three coal beds. The top and bottom beds are 7 to 8 feet thick, but the middle one is 12 feet. The lower beds are separated by a small

[93] L. v. Ammon, "Bayerische Braunkohlen und ihre Verwertung," München, 1911, pp. 9, 10, 63.

[94] J. R. Lorenz, "Ueber die Enstehung der Hausrucker Kohlenlager," *Sitz.-Ber. k. Akad. Wiss. Wien,* Bd. XXII., 1857, pp. 660–664.

interval, but the top bed is usually about 90 feet above the second. Each bed is limited above and below by coaly shale, 2 inches to 2 feet thick, which passes gradually into gray-blue marly clay. The lower beds are double, divided by carbonaceous shale. The parting in the lower bed is 2 inches thick, at 2 to 3 feet from the floor and is known as the "Hohl-lag"; that in the middle bed, known as the "Koth-lag," is almost paper-thin but is persistent. Besides these there occur occasionally in these beds layers of charred material, one third to one half inch thick and termed "Brand-lag"; they are of limited extent and cannot be regarded as partings. As the peculiarities of the beds convinced the author that these are composed of *in situ* plants, he explains the "Brand-lag" as derived from burned vegetable matter—that possibly the surface of the deposit had been ignited by lightning. After the fire had burned out, vegetation began anew. The mass of charred matter is enclosed in unchanged lignite, the separation being sharply defined.

Schreiber[95] has referred to two diluvial moors, one near Piehl in Styria and the other at Hopfgarten in Tyrol. That at Piehl is at 200 meters above the bottom of the present valley and is from one to one and a half meter thick. It underlies 150 meters of conglomeratic materials, and this great burden has so compressed it that it resembles brown coal; but Schreiber objects strenuously to the term Schieferkohle, preferring Schiefertorf, to distinguish it more sharply from the Tertiary brown coal. At Piehl, it rests on a marl; the lowest layer is brown hypnetum peat with loose texture, on which rests reed or rush peat, containing much earthy matter. Then follows a comparatively thick layer of Bruchtorf, composed chiefly of firs and birches. The highest layer is a sedge-moss peat and is thin at all localities examined by Schreiber. Overlying this bed is sandy clay, succeeded by moraine stuff and glacial débris. The Hopfgarten deposit overlies more than 100 meters of glacial débris, from which it is separated by clay bands. It was measured at three places and the thickness seems to be almost constant at about a meter and a half. The lowest portion is Riedtorf, with much mud and consisting mostly of sedges, though, here and there,

[95] H. Schreiber, "Vergletscherung und Moorbildung," etc., pp. 27–29.

reed and brown moss peat are shown. Well-marked Bruchtorf follows, composed mostly of Fichte, though occasional specimens of Scotch fir and birch were seen. According to Zailier, the sedge-moss peat follows, but Schreiber saw only a mere fragment of it. The deposit underlies moraine stuff. The Hopfgarten peat is less like coal than that at Piehl, though both are of the same age. Schreiber explains this by difference in the pressure.

Bursting Bogs.—Peat often remains a long time in the condition of "quaking bog." The floating mat constantly increases in thickness, so that at length it can carry large trees; but, under it, material from the bottom of the mat accumulates slowly and is pulpy. After long-continued rains, water may collect in such quantity as to break the cover and the black mud may be discharged upon lower levels. Lyell,[96] referring to the Solway moss in southern Scotland, states that its surface, covered with grass and rushes, shakes under the least pressure, the bottom being unsound and semi-fluid. On December 16, 1772, having been filled like a sponge during long-continued heavy rains, this bog swelled above the surrounding area and finally burst. A stream of half consolidated black mud crept over the plain with speed like that of an ordinary lava-current. The deluge covered about 400 acres. Tait[97] says that a very great part of the moss of Kincardine is a quaking bog, the peat being so wet as to be semi-fluid. During the process of reclamation, the support for the mass was removed and, on March 21, 1792, the peat began to run on the west side and the flow covered about an acre. On the same day in 1793, the flow was repeated and the peat mud covered nearly 12 acres of the cleared space. The extreme depth of the overflow was 8 feet.

The phenomenon is by no means rare. Lyell conceives that lakes and arms of the sea must occasionally become receptacles of drift peat; and in this way he would explain alternations of clay and sand with deposits of peat, found frequently on some coasts. This explanation would suffice only for some indefinite and insignificant deposits; it is difficult to conceive how the required con-

[96] C. Lyell, "Principles of Geology," New York, 1872, Vol. II., pp. 510, 511.

[97] C. Tait, "An Account of the Peat-Mosses of Kincardine and Flanders, Perthshire," *Trans. Roy. Soc. Edinburgh,* Vol. III., 1794, p. 278.

ditions could exist on great plains; lake deposits are too small to be important in this connection.

The Floor or Mur of Peat Deposits.—In regions where calcareous matter abounds, the floor of peat originating in ponds or lakes is apt to be the familiar lake marl, formed by *Chara* and mollusks, and containing other freshwater forms. Where calcareous matter is lacking, fine clay is the usual floor. Marl and clay are almost impervious; the impression has prevailed that peat grows only on a floor impervious to water.

But marshes and bog deposits may originate on rock of any sort, which is free from constituents injurious to plant life. The great Okefinokee Swamp of Georgia and the much greater Dismal Swamp of Virginia and North Carolina rest, in great part, on sand and in each the peat is thick. The buried peat of the Holland-Belgium-France area has mostly a floor of blue clay, though in many places it rests on sand. Typical freshwater peat may overlie marine sands, clays or limestones. The Carse land peats of Scotland, according to J. Geikie, have as the floor marine sands or marine clays; Moggridge found a similar condition in the Swansea excavations. Rohhumus or Trockentorf, so familiar in our forests, grows on bare rock; even granite may be the floor.

Davis[98] saw "climbing bogs" in northern Michigan, which had grown on smooth glacier polished granite. One, on an isolated rock hill, showed *Sphagnum* in spots, evidently thrifty and making a good growth, but most of the surface was covered with reindeer lichen, both in the open and under trees and shrubs. The peaty cover is thin and fibrous, with little moisture, but this supports the usual trees and shrubs, conifers with white birch and mountain ash as well as some heaths. A small island, with rounded glaciated surface and embracing about 3 acres, rises about 30 feet above Bubbling lake. The peat covering it is usually thin, about one foot but occasionally reaching 3 feet. It is coarse, spongy and brown, contains tree trunks, not thoroughly rotted, along with abundant partially decayed roots and stems of plants. When this locality was examined, the peat was so dry as to burn. The flora consists of the conifer-

[98] C. A. Davis, "Peat," 1907, pp. 264–269.

heath society. An indication of the mode in which peat formation began was observed on the north side of this island, where some spaces of otherwise bare rock were covered with a mat of *Sphagnum* with other mosses and lichens. As soon as these form their deposit, other plants obtain foothold and thenceforward accumulation of peat is continuous, if atmospheric conditions remain favorable. The growth of peat in a region where rain, at times, is wanting for weeks and where the soil is a coarse peat, only an inch or two deep and resting on a smooth rock, is due to condensation of atmospheric moisture in fogs. The plant society of this high, dry peat bed is very closely allied to that which characterizes the older and more mature portions of peat beds with a rock substratum—a confirmation of the belief that both are xerophytic habitats.

Chevalier's[99] observations in the Niger area, between 5° and 9° N.L., show that in that region, at 200 to 400 meters above sea-level, a sedge grows luxuriantly on the bare granite and gneiss, where it attaches itself so firmly as to resist the winds and the tropical rains. There, in hundreds of square miles within French West Africa, this sedge-growth has caused an accumulation of peat, 5 to 30 centimeters thick. The conditions are wholly unfavorable to increase of peat, as there is a dry season, during which the plants wither and the loss is accentuated by fires; yet the surface is covered with a fibrous material, described as very humic.

Ordinarily, however, some organic film is necessary, if the growth is to be rapid. As already stated, those engaged in the peat industry learned long ago that, if peat be removed wholly so as to lay bare the underclay, regeneration of the bog is very slow; but if a thin cover of peat be left on the floor, it is more rapid. The passage from the floor to clean peat may be gradual or abrupt. If the accumulation be in a pond, the transition may be marked by a faux-mur, showing laminæ of sand, clay or marl and peat, or it may consist more or less of the Lebertorf or Sapropel mud. In other types of deposits this faux-mur may consist of alternating peat and silt or sand, evidence of repeated flooding before the peat-forming plants gained the mastery. At times the passage is abrupt,

[99] A. Chevalier, "Les tourbières de rocher de l'Afrique tropicale," *Comptes Rendus,* Vol. 149, 1909, pp. 134–136.

especially where expansion of the bog was by transgression, as is so often observed in plain deposits. The peat itself may be the mur for a new deposit, as where the drying of the upper portion invites invasion by a forest growth, to be destroyed by increasing moisture and return of bog conditions.

A very notable feature of the mur is the abundance at many places of roots and rooted stumps. This has been observed in all parts of the world, and the instances are so numerous that only a few need be cited as illustrations. Tait[100] states that the mosses described by him cover about 9,000 acres. The lowest part of the peat consists very largely of decayed wood, mingled with some black earth and occasional bunches of heather, better developed than those now growing on the surface of the bog. Innumerable tree trunks are at the bottom, lying alongside of their stumps, which, like the heath bundles, are still fixed in the clay. A considerable portion of the moss has been reclaimed by drainage and by complete removal of the peat. The trees at the bottom are oak, birch, hazel, alder, willow and, in one place, a few firs. In one clearing, 40 large oak trunks were found lying by their rooted stumps. These stumps, rooted in the clay, rise about 3 feet and are so little changed that they can be removed only with difficulty. But the stumps of other trees are so badly decayed that little can be said about them except that they are rooted in the underclay. Aiton[101] has remarked that the suggestion that peat deposits originated in forests is abundantly supported by the very frequent occurrence of trees or roots in the underclay. He never had examined a moss of any great extent without finding on its borders and where the peat had been removed "roots of trees still in the ground with their fangs extended as they grew." Along the river Aven, roots of trees are found under every moss "with their shoots firmly clasped into the earth, where they grew." Geikie[102] says that in many mosses, the tree stumps are of approximately uniform height and that the

[100] C. Tait, "Peat-Mosses of Kincardine," etc., pp. 228, 269, 271, 272.

[101] W. Aiton, "A Treatise on the Origin, Qualities and Cultivation of Moss-Earth," Glasgow, 1805, pp. 29, 33.

[102] J. Geikie, "On the Buried Forests and Peat-Mosses of Scotland," *Trans. Roy. Soc. Edinb.*, Vol. XXIV., 1867, pp. 379, 381.

peat grows over the trees which it has killed. A moss on the Isle of Man shows large trees, erect in place, with 20 feet of peat over them.

In 1837, the officers of the Ordnance Survey[103] reported that the lowest layer of fir trees overlies 3 to 5 feet of turf; but not so with the oaks, as their stumps are commonly found resting on the gravel or on small hillocks of gravel and sand, which so often stud the surfaces of bogs.

Reade[104] has shown that a railway cutting through Glazebrook moss exposed 18 feet of peat containing, in a thickness of 3 to 4 feet near the base, remains of trees and branches embedded in the peat. When the peat has been removed, one sees the oak and birch stools rooted in the underclay. A fine overturned tree with roots attached was exposed. It was 46 feet long and 3 feet in diameter just above the root.

Skertchly's[105] observations are equally to the point. In describing conditions in the Fenland counties of England, he says that trees are to be found in the peat everywhere, but that Digby and Bourn for the north and near Ely for the south are the most convenient localities for study. At these places, the trees rooted *in situ* are mostly oaks and are often of gigantic size; in not a few instances, the stems are 70 to 80 feet long and clear to the branch, distinct evidence of forest growth. In one moor he examined an overturned tree, which was 36 feet long with maximum diameter of 30 inches. Bark was preserved on the underside of the tree, but was carbonized and it crumbled into cuboidal fragments. In another fen, oaks are numerous and all are broken off at 2 to 3 feet from the ground, that is at the top of the peat. Some birches were here but only the bark remains; a few elms also, which were

[103] "Ordnance Survey and Report of the County of Londonderry," cited by R. C. Taylor, "Statistics of Coal," 2d ed., 1855, p. 169.

"It is a very remarkable fact, though very common, that successive layers of stumps and trees, in the erect position and furnished with all their roots, are found at distinctly different levels and at a small vertical distance from each other."

[104] T. M. Reade, "On a Section through Glazebrook Moss, Lancashire," *Quart. Journ. Geol. Soc.*, Vol. 34, 1878, pp. 808, 810.

[105] S. B. J. Skertchly, "Geology of the Fenland," pp. 158–162, 167.

recognized by their bark, the wood having decayed. Near Ely, he found a forest of yews, which penetrated the underclay into a thin layer of sand, in which their roots were spread out horizontally; thence the stems passed upward into the peat. In another fen, where the lowest peat is fetid and is known as "bears' muck," he saw a forest of oaks with roots extending into the Kimmeridge Clay below. The stumps, broken off usually at 3 feet from the roots, are associated with the prostrate stems.

Lorié[106] cites Belpaire père to the effect that in Zeeland trees rooted in the subsoil occur frequently in the peat. In discussing the conditions within an area of 1,400 square miles in Holland, Lorié says one finds there one or more peat beds covered with a greater or less thickness of sediment; these are autochthonous and contain stems of trees rooted in the subsoil. He has described a fossil forest near Fochtelos in the great Hochmoor of Smilde, Holland. Formerly, one saw there only a marshy heath; but the surface was lowered by drainage and by cultivation of buckwheat, so that the forest became visible. The trees are oaks with some aspens. The greater proportion of them have been broken off near the surface, probably after death, and the stems lie usually in a southwest to northeast direction. Those examined by Lorié appeared to be rooted in the peat but very near the bottom; but his guide maintained that all the fully exposed stumps seen by him were rooted in the subsoil.

Sections published in works on the Scandinavian swamps show the frequency of trees in the lower part of peat deposits, rooted in the underclay. Von Post[107] has published a photograph of the forest bed in the Tarnsjomoor, which had been exposed by removal of the peat.

Potonié[108] has discussed a great moor near Stelle, which is accessible in dry years. At one locality he saw, underlying 0.03 meter of sedge-peat, on which is one meter of sphagnum-peat, a forest

[106] J. Lorié, *Arch. Mus. Teyler,* II., Vol. III., 1890, pp. 424–427; II., Vol. IV., 1893, p. 183.

[107] L. Von Post, "Die Torfmoore Narkes," *C. R. XIIme Cong. Geol. Int.,* Stockholm, 1912, pp. 1282, 1283.

[108] H. Potonié, "Ueber Autochthonie von Karbonkohlen-Flotzen," etc., *Jahrb. d. k. preuss. geol. Landesanst,* 1895, pp. 25, 26: "Die Entstehung der Steinkohle," *Naturw.-Wochenschr.,* II., Bd. IV., 1905, pp. 7–9.

bed, which is filled with many large and small remains of firs, yews, oaks, birches and alders. The stems are mostly prostrate but with them are many stumps of fir and oak rooted in the bed. The same author, in a later publication, asserts that a Hochmoor may originate on a bed of sand if only there be sufficient moisture. To prove his position, he gives a reproduction of a photograph showing the floor of an extensive Hochmoor, which expanded by encroachment upon a forest growing on sand. The vertical stumps are exposed where the peat was removed.

The condition is familiar in the United States; G. H. Cook, N. S. Shaler, C. A. Davis, D. W. Johnson and others have considered the subject in detail. Davis has described conditions in the Pocosons or swamps on the coastal plain in North Carolina. But there are many peat deposits which did not originate on forested areas; those have no trees rooted in the soil below. There are others beginning in open area but expanding by transgression into a forested area; these have the rooted trees in one portion but not in the other.

It is unnecessary to cite evidence that the peat itself may be a soil for growth of non-water-loving trees. In every land, the peat deposits show successive forest beds, the trees being rooted in the peat and not penetrating to the underclay or subsoil. Numerous instances have been noted in preceding pages. But it is well to emphasize the fact that the opinion that plants have repugnance to thrusting their roots down into peat and that trees do not grow on peat, living or dead, is wholly erroneous. Plants disliking an acid soil certainly do not thrive on peat; but there are plants for which an acid soil is essential. Among these are some of the largest trees of America. That they have grown luxuriantly is certain, for in many of the extensive peat deposits in this country, the peat is commercially worthless because it is so crowded with stumps and stems. In many vast swamps of the coastal plain, a sounding rod cannot be thrust to the bottom and a similar condition has been reported from many places in the interior.

The Roof or Toit.—The roof of a buried peat bog may be as variable as the floor. It may be sand, clay or marl, freshwater or marine; the transition may be gradual, a faux-toit consisting of

alternating laminæ of peat and sediment; or it may be abrupt. Of course, the trees growing on the surface of the bog cannot escape when the bog is killed; if the floods be violent and the winds be high many of the trees, rooted in yielding soil, will be overturned; but if the covering material be conveyed by the ordinary winds or by an overflowing flood, the larger number of the trees will remain erect or at most inclined. Davis[109] has given an illustrative case. He has figured a standing tree trunk seen near Marquette, Michigan. The outer dune at that place had been cut by a storm only a few days before his visit. The waves had undercut the bank and the sand had slipped off, leaving a vertical face. Near the base was a layer of peat, one foot thick, filled with unchanged roots of shrubs and Norway pine. A partly decayed trunk of pine, rooted in the peat, its roots not extending below it, rises 8 feet through the overlying sand. That the accumulation resting on the peat was not due to a sudden overwhelming is clear, for at 2 feet above the peat is a layer of Norway pine needles, while from that to the surface, are irregular layers of sand with roots of trees, grasses and leaves of pine. The accumulation was slow enough to permit vegetable growth at several levels, but the stem did not break away, though the climate is moist. It is possible for trees to remain alive for a long time after a thick cover of porous material has been laid on the surface. Geinitz,[110] has described a forest of great oaks and beeches, growing on a bed of peat and covered in part by a dune. On the surface of the advancing dune, one sees, as it were, thick-stemmed oak and beech shrubs; but these are merely the upper portions of trees, still living, but in great part buried in the loose sand. At Morschwyl in Switzerland, where the overlying deposit is fine-grained, stems 6 feet high project from the peat into the marl above. Berry has described the buried bog on the Chesapeake waters, where the cypress knees pass into the overlying deposit. Seventy years ago, Lesquereux found leaves in the marl overlying peat and the partings of Schieferkohle have plant impressions. These leaves are transported material.

At several localities to which reference has been made, one finds

[109] C. A. Davis, "Peat," 1907, p. 253.

[110] F. E. Geinitz, "Nach der Sturmflut," *Aus der Natur,* Vol. IX., 1908, pp. 76–83.

a succession of peat beds, separated by clay, sand or marl, while peat is forming on the present surface. Some of these beds show trees rooted in the underlying material.

Soils of Vegetation.—The rocks intervening between peat horizons occasionally show what may be termed soils of vegetation, on which plants grew but no peat accumulated. Thomson[111] states that in making excavation for a naval dock in Bermuda, this succession was found, beginning at 25 feet below the surface: (1) Calcareous mud, 5 feet; (2) coral crust, 20 feet; (3) a kind of peat and vegetable soil, containing stumps of cedars in vertical position and the remnants of other land vegetation with remains of *Helix bermudiensis* and of several birds.

This old soil of vegetation rests on the usual "base rock" of the islands. Buried soils of vegetation have been noticed by all students who have visited the Bermudas. They are distinct at several places along the south shore where, in 1895, the dead cedar forest with trunks still erect protruded through the æolian beds, which in many spots were already covered with a dense growth of oleander and young cedars. No peat is found in the Bermudas except in "sinkholes" and estuaries; the porous rock permits rainwater to pass down quickly to tide level so that neither spring nor stream exists on the islands; but one finds buried soils with Helix and plant remains at various levels in the "sandstone" as the slightly consolidated æolian rock is termed.

Hilgard[112] saw, near Port Hudson on the Mississippi, brown muck overlying white or blue clay and underlying 93 feet of later deposits. This muck, 3 to 4 feet thick, contains cypress stumps, representing three, perhaps four generations. The stumps are rooted in the tough, somewhat sandy underclay. A similar deposit was seen at many places within lower Louisiana and usually several generations of cypress trees are shown. At one locality, huge stumps, 5 to 8 feet high, have their roots buried in a stratum of brown clay; the tops of

[111] C. W. Thomson, "The Atlantic," 1878, Vol. I., pp. 297, 298.

[112] E. W. Hilgard, "On the Geology of Lower Louisiana and the Salt Deposit on Petite Anse Island," *Smithson. Contrib.*, No. 248, 1872, pp. 5, 6, 7, 9, 11, 26.

the stumps are surrounded by similar clay but the middle portion is enveloped in yellow silt. A reddish loam is the superincumbent material to the surface. At about a mile below the Port Hudson locality, a deposit was seen, 30 feet above the stump horizon and resembling a river sandbar both in structure and contents. There, one finds no stumps but abundance of large drifted stems belonging to several species and some of them erect. These last, as Hilgard describes them, can be no other than "snags," which are even now only too numerous on sandbars along the river's present channel. At many places one finds living cypress swamps on the newer deposits.

The deep oil wells of the delta, according to Harris,[113] have proved that there are many muck beds in the Recent deposits of the delta region.

A section measured by Colenso[114] in the tin-producing area of Cornwall shows features not unlike those observed by Hilgard near Port Hudson: the succession is (1) Bed of river sand and gravel, 20 feet; (2) sand, containing tree trunks lying in all directions and mostly oaks, with bones of various mammals, red deer and whales, 20 feet; (3) silt or clay, 2 feet; (4) sand with marine shells, contains salt, 4 inches; (5) sludge or silt, contains recent shells and bones of mammals, 10 feet; (6) dark silt mixed with decomposed organic matter, about 12 inches, on which is a layer of leaves, hazel nuts. sticks and moss, 6 to 12 inches, this mass is apparently in place of growth and extends with some interruptions across the valley; (7) tinground, thickness varying according to irregularities of the underlying rock surface. Roots of trees are seen in this "ground" and on top of it oyster shells still remain fastened to some of the larger stones and to stumps of trees. The roots of oaks are in their normal position and can be traced to their smallest fibers, even as deep as 2 feet.

Here one has the soil of vegetation with its trees while, above it, are layers containing drifted logs and others of distinctly marine origin. It is worth noting that, at Sandycock in the same district,

[113] G. D. Harris, Geol. Surv. of Louisiana, Rep. for 1905, pp. 233, 240.

[114] J. W. Colenso, "Description of Happy-Union Tin Stream-work at Pentuan," *Trans. R. Geol. Soc. Cornwall,* Vol. IV., 1832, pp. 29–39.

Rashleigh[115] found 4 feet of peat in the upper part of the section, while the merely vegetable soil of Colenso's section is "solid black fen."

The presence of trees unassociated with peat has been regarded by some as evidence of allochthonous origin, as reforestation of an area after entombment of the peat seemed improbable. But reforestation is comparatively rapid on a new surface, provided only that there be moisture. During the great Missouri River flood of 1903,[116] the water, diverted from the channel by obstructions piled against a railroad bridge, swept over a wide area. Crops were ruined and a nursery field, near Topeka, Kansas, was covered with sand, which buried the young trees. But within three months, the naked fields were green with young cottonwoods, growing from seed blown in after subsidence of the flood waters. Even dunes, consisting of loose sand, become covered with vegetation and eventually with forest.

Reforestation is rapid even amid untoward conditions. Seventy-five years ago, the White Mountains of New Hampshire were covered with a dense forest, mostly spruce. Lumbermen denuded a very great part of the surface and their labors were supplemented by forest fires, which destroyed trees elsewhere. Where the soil was burned off, so as to be washed away and to expose the glaciated surface, nothing grew; but elsewhere the restoration was rapid. Plants of various types took prompt possession and prevented erosion. They were succeeded by birch and cherry, in whose shade the conifers grew. On the neglected farms of that region, one finds all stages of restoration, from pasture lots invaded by sturdy weeds to the forest of firs and spruces, which have overcome the birches. The conditions are similar in Ontario, as Miller and Knight[117] have shown. Their statement respecting one area is:

"Years ago, the area was visited by heavy fires which destroyed all but a few of the pine trees that were numerous and made the area important for its timber. On the part of the lake referred to, a few red pines and one or

[115] P. Rashleigh, "An Account of the Alluvial Depositions at Sandrycock," *Trans. R. Geol. Soc. Cornwall,* Vol. II., 1822, p. 282.

[116] H. C. Frankenfield, "The Floods of the Spring of 1903 in the Mississippi Watershed," Bull. M, U. S. Weather Bureau, 1904, p. 62.

[117] W. G. Miller and C. W. Knight, "Pre-Cambrian Geology of Southeastern Ontario," Toronto, 1914, p. 18.

two white ones escaped the fire and were left as seed trees. Poplars have since grown up and now have a height of fifty or sixty feet or more. Back from the shore, where the seed has been blown, in the shade of the poplars, there is now a pretty growth of young pine trees, four or five feet in height."

In a letter, W. G. Miller states that the condition is familiar in many portions of Ontario.

Rock streams may still be seen at many places in the Allegheny mountains and in their path the forest has been removed. But even these coarse breccias become covered. Agnew[118] says that, when he returned by canal from Harrisburg to western Pennsylvania, he observed long stretches of stone-covered mountain side, bare of all vegetation from base to summit, the slope varying from 25 to 40 degrees. In later years, coming to Harrisburg to sit on the Supreme bench, he could find none of the naked spaces. The rocky surface had become covered with trees, the few remaining bare spaces being merely dots in the forest. The writer may add his testimony to the same effect. Rock streams are not wanting now in the Allegheny Mountains but they are not those, which were striking features in the scenery forty years ago; they are of later origin.

Forest growth may appear quickly after an area has emerged from marine conditions. One finds dense forests and great peat deposits directly on Post-Pliocene marine beds at many places along the Atlantic coastal plain of the United States. Darwin[119] saw on the island of Chiloe a bed of marine shells, the species being *Venus costellata* and *Ostrea edulis,* both now living in the adjacent bays. These were closely packed, embedded in and covered by a very black, damp, peaty mould, 2 to 3 feet thick, out of which a great forest of trees was growing.

It has been shown that forests on plains or even on rolling surfaces may bring about formation of peat deposits, but this does not occur always. Trees growing on peat have been entombed, others not associated with peat have met similar fate. River deposits have overspread extensive areas of forest, so that one finds in the rock

[118] D. Agnew, "Nature's Reforesting," *Proc. Amer. Phil. Soc.,* Vol. XVIII., 1878, pp. 26, 27.

[119] C. Darwin, "Geological Observations in South America," London, 1846, p. 28.

separating peat beds, trees singly or grouped, growing from an ancient soil with but small accumulation of offal about the stems. The buried forests of Oregon and Alaska, described by Newberry and Russell, are typical. Medlicott's[120] résumé of Ormiston's observations may be noticed in this connection, as they show how a forest, growing in an old soil of vegetation, may be succeeded by a marine deposit, while the stems remain erect. Excavations for a government dock were made on Bombay island off the west coast of India. In a space of about 30 acres, 382 trees and stumps were uncovered, of which 223 were erect. Some of the prostrate stems were without roots but others had been overthrown in place, for the roots were still embedded in the soil. The stumps are rooted in a thin soil of decomposed basalt and are surrounded by a stiff blue clay on which rests black marine mud, 4 to 5 feet thick. Stumps projecting above the clay into the black mud have been drilled by Teredo; in some cases the holes pass downward through the trunk toward the root and are filled with indurated clay. The trees are *Acacia catechu;* how far the forest extended is unknown, as no investigation was made beyond the limits of the excavation.

The opinion, that stems of trees would not endure while a considerable thickness of rock accumulates, is based on very serious misapprehension of the facts or on *a priori* reasoning. The writer has seen slender canes standing erect near the mouth of the Mississippi River, though they had been dead long enough to permit deposition of several feet of fine silt around them. Weed[121] has shown that the Yellowstone Park diatom deposits cover many square miles. A typical marsh is in the Upper Geyser basin, where the waters encroached upon the timber and killed the pines, whose bare gray stems stand upright in the marsh or lie half immersed in the ooze. The diatomaceous earth is sometimes 6 feet thick and the "gaunt poles of the dead pines stand in a white powdery soil, which is evidently a dried portion of the marsh mud."

[120] G. E. Ormiston, cited by H. B. Medlicott, Records Geol. Surv. of India, Vol. XIV., 1881, pp. 320–323.

[121] W. H. Weed, "Diatom Marshes and Diatom Beds of the Yellowstone National Park," *Bot. Gaz.*, Vol. IX., 1908, pp. 76–83.

Wright[122] has described the buried forest near the Muir glacier in Alaska. This was deeply buried under gravels, over which the ice extended at a later period. The ice retreated and erosion began, which eventually uncovered the forest. The trees are of large size, mostly like those now growing on the Alaskan mountains and are in a state of complete preservation. These are standing upright in the soil on which they grew, with the humus still about their roots. Some are exposed throughout while others are shown only in part. Many are broken off at from 5 to 20 feet above the roots; Wright thinks this fracturing due to cakes of ice, that being indicated by scars on the trunks. Russell,[123] writing about a portion of Alaska farther west, states that the Yahtse River, issuing as a swift current from beneath a glacier, has invaded a forest at the east and has surrounded the trees with sand and gravel to a depth of many feet. Some of the dead trunks, still retaining their branches, project above the mass, but most of them have been broken off and buried in the deposit. Other streams east from the Yahtse have invaded forests, as is indicated by dead trees standing along their borders. Where the deposit is deepest, the trees have already disappeared and the forest has been replaced with sand flats. The decaying trunks are broken off by the wind and the stems are buried in prostrate position. Nordenskiold,[124] in discussing the distribution of trees in the Yenesei region says:

"Besides these there are to be found in the most recent layer of the Yenesei tundra, considerably north of the present limit of actual trees, large trees with their roots fast in the soil, which show that the limit of trees in the Yenesei region, even during our own geological period, went farther north than now, perhaps as far as, in consequence of favorable local circumstances, it now goes on the Lena."

Resistance to Erosion.—The opinion, that trees would be uprooted and carried away by the strong current of a flood, is not well-supported as a generalization. The instances cited from Russell and Wright would seem to suffice in refutation and the writer has dis-

[122] G. F. Wright, "Ice Age in North America," 1889, pp. 57–59.

[123] I. C. Russell, "Second Expedition to Mount St. Elias," Thirteenth Ann. Rep. U. S. Geol. Surv., 1893, Pt. I., p. 14, Pl. XII.

[124] A. E. Nordenskiold, "The Voyage of the Vega," p. 287.

cussed the matter somewhat in detail elsewhere.[125] But it may not be amiss to cite some additional evidence showing that floods and torrents are almost powerless against living vegetation. In the summer of 1895, the writer was marooned during three days by a flood on the Little Wichita River of northern Texas. The flood was widespread, affecting also the area of the Brazos River. It came abruptly, so that in a single night, the petty streams, flowing at 30 to 40 feet below the general level, filled their little valleys and overflowed; the parched area of the preceding day was covered with water more than hub-deep in many places. The current was extremely rapid; by mistake of the guide, the party were caught in it on one stream and narrowly escaped being swept away with the horses and the heavy conveyance. Within 2 miles of the city of Archer, the flood had invaded an extensive area, covered with trees and shrubs. Rapid outside, the movement was insignificant within this wooded area, the trees and shrubs, though not dense, being as efficient in checking the motion and in breaking up the current as is débris in a mountain forest. After cessation of rain, the flood subsided almost as quickly as it had risen. A ride of 60 miles over the area affected by it gave ample opportunity for studying the effect. The roads and sandy places were gashed and gullied; cultivated fields in the line of the torrents, one eighth to half a mile wide, were swept clean of the thin cover of soil, but where the surface was protected by grass the destruction was unimportant. Trees and shrubs, except those standing on loose material, were uninjured, while in extensive clumps of bushes there was no evidence of disturbance, aside from an accumulation of débris, deposited where the current first reached the plant-obstruction. The fierce current was powerless against trees, even against the clumps of bushes.

Reade,[126] writing of floods on the Senegal and Gambia Rivers, says:

> "If a boat was to be moored in the rivers to the top of an acacia tree just projecting above the water, you would find it afterward in the dry season hanging forty feet above your head."

[125] See "Formation of Coal Beds, II.," *Proc. Amer. Phil. Soc.*, Vol. L., pp. 520–546.

[126] W. W. Reade, "Savage Africa," New York, 1864, p. 363.

After these violent floods have abated, the forests are seen practically uninjured by their brief submergence. The remarks by Harris[127] are in place here. The Hawash River rises in the Abyssinian highlands at 8,000 feet above sea-level. In the dry season, it can be forded easily but during the rainy season it is often converted into a fierce torrent inundating the broad valley, which is covered with trees and dense undergrowth, through which the explorer makes way only with great difficulty. When the expedition approached this river, it was very evident that there had been a flood, as "pensive willows that drooped mournfully over the troubled current, were festooned with recent drift, hanging many feet above the level of the abrupt banks." The condition was very similar to that observed by the writer in going by steamboat from San Francisco to Sacramento, almost 50 years ago. He was perplexed by the presence of clumsy débris in branches of trees at about 15 feet above the water. This marked the level of the floods.

The Ohio Valley flood of March–April, 1913,[128] was one of the most disastrous recorded. The damage to the towns of southeastern Ohio, as stated by Horton and Jackson, was almost 147,000,000 dollars, 36,000 buildings were flooded or destroyed and 220 bridges were carried away. The report is illustrated by 22 plates, showing conditions during and after the flood in several large cities, which suffered most severely. These show that trees in the streets resisted not only the current but also the débris carried by the water; houses and timber were piled around the trees and even the telegraph poles. One of the photographs gives ample proof that this was no gentle backwater overflow but a typically torrential movement.

The tenacity with which trees resist removal by floods is, to use a moderate term, remarkable. For many years the writer has ridden annually for more than 200 miles along the Connecticut River in June and September. In many places, trees cover the face of first terrace, extending frequently to within 18 inches from the line of low water. The terrace or "first bottom" is composed of uncon-

127 W. C. Harris, "The Highlands of Ethiopia," Amer. ed., New York, 1844, pp. 94–96.

128 A. H. Horton and H. J. Jackson, U. S. Geol. Survey, Water Supply Paper, No. 334, 1913.

solidated river drift, which where unprotected is attacked energetically by the current. The trees along the lower portion of the bank have roots almost horizontal, as the wet ground is little more than a foot below the collar. In very many cases the roots are exposed to a distance of two to three feet from the trunk, the loose material originally surrounding them having been removed. Several of these trees have been observed each year, during ten years the exposed portion has increased steadily, but the trees have continued to grow and apparently they are as solidly fixed as at first.

But in the sands under and over peat deposits as well as in rocks contemporaneous with such deposits, one finds logs, even tree stems with attached roots. Rivers undercut their banks, trees and plant débris fall into the water and are transported. Some of this material is carried to the sea, there to decay, but some is dropped in shallows or stranded on the river plain during subsidence of the flood, to be covered by deposits brought by succeeding floods.

Contemporaneous Erosion.—Little rivulets are seen in the smaller bogs, but great swamps, in which peat is accumulating, are more or less imperfectly drained by rivers with sluggish flow. The streams are subject to floods, during which they bring down more or less organic material mingled with plant débris. Much of this is deposited in the channelway and much of the rest is spread over the flooded portion of the swamp. Sometimes an obstruction dams the stream and diverts its course, leaving below the dam a stagnant pool, which in time becomes concealed by peat; but the story is revealed when a drainage canal is cut, for the half-filled channelway is shown by a "roll" in the underclay. The drainage system is often distinct in a buried bog. Lorié's[129] observations in the peat region of Holland-Belgium prove that the channels of large rivers have been filled with sediment and that these are traceable easily when the records of borings have been platted.

Banks of the intersecting streams are irregular, as plants spread out into the water, often becoming floating fringes. When the channelway is filled gradually by deposit of inorganic matter, the fringes are not torn away but are enveloped in approximately normal

[129] Cited in "Formation of Coal Beds, II.," *Proc. Amer. Phil. Soc.*, Vol. L., pp. 617–619.

position, to be exposed as irregular strings of peat when laid bare by a drainage canal. If, however, the filling be abrupt and violent, masses of the peat are rubbed off to be embedded in the sand, while the adjacent portion of the bog is very apt to show crushing or folding.

Filled channels occur frequently in rocks associated or contemporaneous with the peat deposits. The Missouri and Mississippi Rivers have shifted the channels at many places and the abandoned "ox-bows" in numerous instances have been filled with material different from that of the banks. The rivers of the Gran Chaco of Paraguay and Argentina flow in constantly shifting channels, the older ways becoming filled to be exposed by a new change in direction of flow. A. Geikie[130] has described several cases of channels in the drift beds of Scotland, eroded and refilled during the Glacial period. Others have been noted by J. Geikie and by J. Croll.

Some Chemical Features of Peat.—It is well known that mature peat, when first taken out, is plastic; but when thoroughly dried it is no longer plastic. The same effect is said to be produced by freezing. It is evident, as said by v. Gümbel more than thirty years ago, that peat contains some substance, which is soluble in the fresh condition but is insoluble when dried. Microscopical study of mature peat shows that the minutely divided vegetable matter is accompanied by an amorphous substance, sometimes so abundant that the fragments appear to be cemented by it or even to be embedded in it. The earliest reference to this substance, known to the writer, is that by Reinsch,[131] who stated that in the Fichtelgebirge there are two kinds of peat, Rasen- and Pechtorf. Rasentorf occurs in thick deposits, 2 to 12 feet, but Pechtorf is in thin layers, as shown in his material from near Rautengrün on the left bank of the Eger river. The latter feels damp, almost greasy, is about twice as heavy as Rasentorf, has lustrous, brown-black surface and consists of roots embedded in an almost black substance.

Definite information respecting this material seems to be due

[130] A. Geikie, "On the Glacial Drift of Scotland," *Trans. Geol. Soc. Glasgow,* Vol. I., Pt. II., 1868, pp. 65 ff.

[131] H. Reinsch, "Ueber den Torf des Fichtelgebirge," *Journ. f. pr. Chemie,* Vol. XVI., 1839, pp. 489–495.

to Doppler,[132] who stated that he had received from Salzburg, in Tyrol, about 15 pounds of a black gelatinous substance, which had been obtained near Aussee in a peat bed, about 10 feet thick. It occurred in layers at 6 to 8 feet from the surface and it had been rejected as worthless. Schrötter,[133] who studied this chemically, ascertained that, dried at 100° C., it lost 78.5 per cent. of water and became a hard mass with conchoidal fracture and vitreous luster, resembling greatly the pitch obtained by distillation of coal tar. Dried at ordinary temperature, about 18° C., it parted with 66.22 per cent. of water. The wet gelatinous material lost 14.6 per cent. to caustic potash, equivalent to 68 per cent. of the dried material, but when dried, it lost nothing to the potash solution. Hydrochloric acid precipitated from this solution a brown substance which, dried, contains; Carbon, 48.06; hydrogen, 4.98; nitrogen, 1.03; oxygen, 40.07; ash, 5.86.

If ash and nitrogen be ignored the composition is, compared with that of cellulose,

Carbon	51.59	43.24
Hydrogen	5.34	6.30
Oxygen	43.03	50.56

The presence of ammonia is evident when a fragment is boiled with caustic potash. He recognized in this gelatinous substance simply a more than usually homogeneous peat, owing its gelatinous character to the great quantity of absorbed water.

At the same meeting, Haidinger[134] discussed the mineral relations of this material, to which he assigned the name, Dopplerit. It is amorphous, but thin sections, under strong power, show the presence of fine fibers in the mass. One of the pieces received from Doppler enclosed fragments of unchanged peat, in which *Phragmites communis* was recognized. Haidinger believed that this structureless peat is the beginning point of the whole series of changes, which up to that time had been wholly conjectural.

[132] Doppler, "Ueber ein merkwurdige in Oesterreich abgefundene gelatinöse Substanz," *Sitz.-ber. k. Akad. Wiss. Wien,* 1849, Bd. 3, Abt. 2, p. 239.

[133] Schrötter, the same, pp. 285–287.

[134] W. Haidinger, the same, pp. 288–292.

Von Gümbel[135] made an elaborate study of Dopplerit in 1858. He found that the Berchtesgaden dopplerite differs in some respects from that of Aussee. After drying in air, it gives off 12 per cent. of water at 100° C.; when heated to red heat in a closed vessel, it yielded 66.33 per cent. of non-coherent coke, retaining the form of the original fragments. The ash is but 1.67 per cent. of the dried material and consists mostly of lime. Treated with absolute alcohol, it yields a considerable quantity of resinous matter, which v. Gümbel thinks consists of two resins. The variability of composition at different localities leads him to believe that dopplerite is not a true mineral, but is merely a homogeneous peat and he suggested instead the term Torfpechkohle because of its resemblance to the Tertiary Pechkohle. The mode of occurrence at Berchtesgaden is peculiar, the succession in the pits being (*a*) Rasen- and Moorerde; (*b*) Specktorf; (*c*) Fasertorf; (*d*) Specktorf; (*e*) Fasertorf with roots; (*f*) gray marl; (*g*) calcareous pebbles. (*f*) is almost impervious to water. The Torfpechkohle is found chiefly between (*d*) and (*e*), but (*c*) contains much of it in irregular streaks. Two vein-like branches pass upward from the main deposit overlying (*e*) and continue through the higher benches into (*a*). He is convinced that the material was soft and that under pressure it flowed into crevices. This feature suggested that plant materials were softened as one step in the conversion into coal.

Kaufmann[136] received specimens of a lustrous black coal, occurring in a peat layer at Obburgen in Unterwalden, Switzerland. It agrees with dopplerite in all essential features. The material was from a Hochmoor, where it was found at 12 to 14 feet below the surface and in masses 6 inches to a foot thick, embedded in the black peat; but it often occurs as veins, streaks or nests. When fresh, it is gelatinous but it becomes hard on drying; it is odorless, has greasy luster and mahogany streak; softer than talc, it cracks under pressure. Examined under the microscope it is homogeneous,

135 C. W. v. Gümbel, "Ueber das Vorkommen des Torf-Pechkohle (Dopplerit) im Dachelmoos bei Berchtesgaden," *Neues Jahrbuch,* Jahrg. 1858, pp. 278–286.

136 F. J. Kaufmann, "Ueber den Dopplerit von Obburgen und über das Verhaltniss des Dopplerit des Torf und mineralischen Kohlen," *Jahrb. k. k. Geol. Reichsanst.,* Bd. XV., 1865, pp. 283–290.

but there are some fine granules, more or less transparent, and occasional traces of cell structure. Under water, dopplerite remains unchanged for years. Once dried, it is equally stable; when wetted again, it may soften so as to show the print of the finger nail, but no farther change appears after several months.

Muhlberg analyzed four specimens, three from Obburgen and one from Aussee the original locality. In all the carbon is higher while oxygen and nitrogen are lower than reported by Schrötter. The difference was enough to induce Muhlberg to make additional study. The material was treated with caustic potash and the dissolved substance was analyzed. It is richer than dopplerite in carbon. Kaufmann finds evidence that the varying composition is due to varying extent of change in the vegetable matter. Peat examined in thin slices shows sufficiently well the organic structure but it contains bright specks, soluble in boiling caustic potash; these are very rare in young peat but are abundant as nests in mature peat. This dissolved material acts as that dissolved from dopplerite. The proportion dissolved by caustic potash increases with the age of the peat, as shown by the following results of Kaufmann's experiments: 25 to 30 per cent. from peat directly under the living plants; 54 per cent. at 3 feet below the surface, loose; 55 per cent. at 6 feet below the surface, darker, fibrous; 65 per cent. 9 feet below the surface, coffee-brown, compact, comparatively heavy. Blackish-brown, heavy, compact peat with black pitch-like streak yielded 77 per cent.

According to Billingsley's[137] notes, the peat of the South Marsh, 3 to 15 feet thick, is accompanied by a pitch-like substance, which occupies the spaces between the vegetable fragments.

Zincken cites von Tschudi (1859) to the effect that dopplerite is found in Switzerland near Bad Gonten in Canton Appenzell, where, beyond the depth of 9 feet, it occurs in streaks up to 5 inches thick. Humus acid flows from this and hardens to Pechkohle; he cites J. W. Herz as authority for this composition of dopplerite: Water, 15.03; ash, 3.39; carbon, 57.47; hydrogen, 5.32; oxygen,

[137] Cited by H. B. Woodward, "Geology of Eastern Somerset," etc., 1876, p. 156.

36.25; nitrogen, 0.86. The material analyzed was air-dried; the ultimate composition as given is ash and water free.

Demel,[138] studying dopplerite from the original locality, found that it would not give up all its water at less than 120° C.; but this high temperature should not be prolonged, as decomposition begins quickly. His specimens contained no nitrogen, thus differing from those analyzed by Schrötter and Muhlberg. The ash varies little from 5 per cent. The carbon approaches that obtained by Kaufmann but is nearly 5 per cent. more than that reported by Schrötter, with also an increase of 0.4 per cent. in the hydrogen. He assigns the formula of $C_{12}H_{14}O_6$ to dopplerite. A large part of the mineral is soluble in caustic potash, from which it may be precipitated by acids. This precipitate has less hydrogen, the formula as determined by Demel, being $C_{12}H_{12}O_6$. The ash, 5 per cent., contains 72.67 per cent. of calcium oxide, equivalent to about 3.63 per cent. of the dried dopplerite, along with 12.02 per cent. of alumina and ferric oxide.

Von Gümbel in his later study, recognized the calcareous nature of the ash, which is snow-white; he thinks there may be a chemical combination of the calcareous and organic constituents.

Früh's[139] discussion was more elaborate than that by any one of his predecessors. He compared the features of dopplerite from many localities. It is present throughout some peats as brown flakes, one centimeter to a decimeter, giving a mottled appearance to the mass, which he terms Marmortorf. He found it only in Rasentorf (grass and sedge), or at the junction between Rasen- and Hochmoor (Sphagnum peat); that is to say, only in peat rich in water, a condition which favors ulminification. Dopplerite and peat are not separated sharply, there being always a passage zone. Evidently the dopplerite was fluid; it is associated frequently with a twig or root, along which it flowed; sometimes, it is in thin sheets; it may fill preëxisting cracks in the peat or in the underlying materials. The calcareous ash led him to believe that it is present in the Rasentorf because that thrives in calcareous water, whereas *Sphagnum* does not; at the same time, *Sphagnum* is convertible into

138 W. Demel, "Ueber den Dopplerit von Aussee," *Sitz.-ber. k. Akad. Wiss. Wien,* 1883, Bd. 86, Abt. 2, pp. 872–878.

139 J. J. Früh, "Ueber Torf und Dopplerit," Trogen, 1883, pp. 64, 68, 69–72.

dopplerite, for Früh saw dopplerite of sphagnum origin at the junction of Hoch- and Rasenmoor, where the water was very abundant. He objects very strongly to regarding the material extracted by caustic potash as the true dopplerite; he believed the mineral to be an ulmin product; the potash dissolves both ulmin and humin products. Dopplerite, according to Früh, is most abundant in the lower portions of a deposit, but the microscope detects flakes of ulmin-like material throughout the mature peat. It is well to recall here the fact observed by C. A. Davis in Michigan and by Dachnowski in Ohio, that *Sphagnum* is indifferent to the character of the water, limy constituents not interfering with its growth. Equally, Rasenmoors do not require calcareous waters, for the water of the Rhine and of the Meuse is thoroughly fresh. Kinahan, in 1861, referred to the tarry fluid which trickled from an Irish bog—evidently dopplerite.

H. L. Fairchild in 1881 and Lewis in 1882 described a dopplerite-like substance obtained near Scranton, Pennsylvania. Lewis's[140] description is the more in detail. This substance is in swamp muck at the bottom of 8 to 10 feet of peat and occurs in irregular veins. It is black and jelly-like when fresh, but on exposure becomes tougher and more elastic. Caustic potash dissolves it. Analyzed by J. M. Stinson, it proved to contain: Carbon, 28.989; hydrogen, 5.172; nitrogen, 2.456; oxygen, 56.983; ash, 6.400. The formula as determined from the analysis seemed to be $C_{10}H_{22}O_{16}$. There is little combined nitrogen as the quantity of ammonia is small.

Foster[141] studied a substance which appears to be very closely allied to dopplerite. The deposit is in northwestern New Mexico along a broad "wash," draining into the canyon of the Chaco River. Its existence was indicated first by a Navajo Indian, who said that wherever the Indians had sunk wells within an area, 10 miles long and of considerable width, they had encountered this material. The collector reported that normally it underlies clay and soil, but sometimes the clay is absent. At the first test pit, clay is absent and the

[140] H. C. Lewis, "On a New Substance Resembling Dopplerite, from a Peat Bog at Scranton," *Proc. Amer. Phil. Soc.*, Vol. XX., 1882, pp. 112–117.

[141] W. Foster, "A Remarkable Carbonaceous Deposit near Putnam, New Mexico," *Econ. Geol.*, Vol. VIII., 1913, pp. 360–368.

deposit, there liquid, was reached at 3 feet from the surface. It ran into the pit as rapidly as it was baled out. Four miles away on the same wash, a second pit reached, at 3 feet, one foot of clay resting on the deposit, more than 10 feet thick, the bottom not reached. At this locality, the substance has the consistence of gelatin, becoming denser with increasing depth. Dried, it is black, brittle, hard and, when powdered, resembles coal dust. In two trials, the material yielded 59.69 and 53.74 per cent. of water. Burned at a low temperature, it left 53.53 per cent. of ash, containing 3.03 of lime and 9.39 per cent. of soda. Ignoring the ash, the composition is: Carbon, 56.04; hydrogen, 6.76; nitrogen, 2.04; oxygen, 35.16, which approaches very closely to the composition of dopplerite analyzed by Herz, Kaufmann and Demel. The ash is apparently a silicate of aluminium and sodium; it is very finely divided and shows no trace of diatoms; Foster suggests that it may be chiefly disintegrated soda-feldspar. Jeffrey[142] examined the substance under the microscope; he found no trace of organic structure but crystalline mineral matter is present.

It is certain that peat contains an amorphous substance derived from the vegetable matter. This, originally more or less soluble, becomes insoluble when deprived of its water. The quantity is small in the newer peat but increases downward, being most abundant in the mature peat, where in many cases the vegetable fragments appear to be embedded in it. Its composition is variable, being dependent, apparently, upon the extent of chemical change in the plant material.

Composition of Peat.—In all works treating of general geology, one finds tabular comparison of the fossil fuels, based on the average of a great number of analyses. One may not deny the utility of an "average," when the averaged analyses are all from one mine on a bed of coal, the desire being to ascertain the general grade of the material as shipped. Yet even in that case, the defects in the method become painfully evident to the man, who having purchased on the basis of the average, receives coal from the less desirable portions of the mine. "Peat" is a generic term including products

[142] E. C. Jeffrey, letter of December 19, 1914.

of vegetable matter undergoing a chemical change which differ in composition according to the extent of that change, according to the nature of material and according to the conditions under which the change was made. Many matters have to be considered; if these be ignored, the comparison is worthless.

All writers on peat deposits have called attention to the fact that a notable physical change is observable as one follows the peat downward from the surface, the disintegration of vegetable matter increasing so that in the great mass of the mature peat, little trace of organic matter can be recognized by the unaided eye, while in many respects the lower portion bears much resemblance to brown coal. The specific gravity increases with this change. Mills and Rowan[143] state that young Hanoverian peat has the gravity of 0.113 to 0.263, whereas that of the maturer peat is from 0.639 to 1.039. The chemical change is gradual but more and more marked with increase of depth. Cornet[144] has given three illustrative analyses as follow:

	C.	H.	O.	N.	Ash.
Surface	57.75	5.43	36.06	0.80	2.72
Two meters and one half	62.02	5.21	30.67	2.10	7.42
Four meters and one half	64.07	5.01	26.87	4.05	9.16

The ultimate composition is calculated ash and water free. The extraordinary increase of nitrogen in the lowest portion may be due in part to the presence of some plankton materials. Jentzsch[145] says that in the province of Preuss, the peat deposits vary in thickness from a few inches to 17 meters. The composition of a peat used for fuel is, water free: Carbon, 56.90; hydrogen, 5.54; oxygen, 31.88; ash, 5.66. In his later publication he compares peat from several localities in the same province, thus:

[143] E. J. Mills and F. J. Rowan, "Fuel and its Applications," 1889, p. 18.

[144] J. Cornet, "La formation des Charbons et des petroles," Extrait de l'ouvrage, Geologie, T. III., p. 25.

[145] A. Jentzsch, "Die geognostische Durchforschung der Provinz Preussen im Jahre 1876," *Schrift. k. Phys. Okon. Gesell. Königsberg,* Jahrg. 17, 1877, pp. 120, 122; "Ueber die Moore der Provinz Preussen," the same, Jahrg. 19, 1878, pp. 128–131.

	C.	H.	O.	N.	Ash.
Surface peat................	49.90	5.80	42.80		3.50
Denser peat................	57.50	6.90	31.87	1.75	2.08
Dense peat..................	62.15	6.29	27.20	1.66	2.70

Mills and Rowan[146] have given analyses of surface and dense peat from three localities in Ireland,

	C.	H.	O.	N.
Surface peat..............	58.694	6.971	32.883	1.451
"	59.920	6.614	32.207	1.258
"	60.018	5.875	33.152	0.954
Denser peat	60.476	6.097	32.546	0.680
"	61.022	5.771	32.400	0.807
"	61.247	5.616	31.446	1.690

In the region whence these samples were taken, the growth of peat has been very slow during a long period, so that the surface peat, or rather, that from near the surface has undergone much greater change than that in similar position within areas where growth still continues. The same authors give results obtained by Woskresensky who analyzed Russian peat, which evidently came immediately under the growing surface; it contained about 41 per cent. of carbon with 54 per cent. of oxygen and nitrogen.

Mulder[147] analyzed fuel peats from localities in Holland and found the carbon varying from 59.27 to 61.05 per cent. and the oxygen from 32.50 to 34.71 per cent.

Zincken[148] has given the results of two analyses of Schieferkohle from Utznach, in Switzerland; the first is of the ordinary material, but the second is of a dense coal, hard, almost black and with conchoidal fracture;

	C.	H.	O.	N.
I......................	55.27	5.70	36.84	2.19
II......................	56.04	4.70	36.07	2.19

146 "Fuel and its Applications," p. 20.

147 G. J. Mulder, "Ueber das arabische Gummi, die pectische Säure und die Zusammensetzung der Torfarten," *Journ. f. pr. Chemie,* Vol. XVI., 1839, p. 246.

148 "Physiographie der Braunkohle," p. 24.

If one may make a suggestion on the basis of these results, it would seem as though mere pressure has had little influence here, for the hard Schieferkohle of Utznach contains much less carbon than is found in some mature recent peats.

Von Ammon[149] has published an analysis of Schieferkohle from Grossweil in Bavaria, which, reduced to pure coal, shows: Carbon, 60.59; hydrogen, 4.86; oxygen and nitrogen, 34.55. The ash is 8.21. This coal, according to v. Ammon, is to be regarded as an earthy brown coal with inclusion of lignite ("bituminous wood"). It is of the same age as the Utznach Schieferkohle. C. A. Davis has given a long series of analyses from American localities, to which reference will be made in another connection. It suffices here to note than in four samples, with ash varying from 3.84 to 6.69, the carbon varies from 51.8 to 59.5 and the oxygen from 41.4 to 32.6, the determination being on basis of pure coal.

Peat, according to its age and its place in the deposit, may vary in carbon-content from much less than 50 per cent. in the upper portion to more than 64 per cent. in the mature portion, the calculation being on basis of the pure fuel. The more mature the peat, by so much the more it resembles brown coal in chemical and physical characters.

Nitrogen is present in all peats, of which analyses have been published. The analyses by F. M. Stanton, which have been tabulated by Davis,[150] make this clear for the United States. The quantity bears no relation to that of the ash. Peat from Leon county, Florida, has 4.28 of ash and 2.30 of nitrogen, while another from Lake county in the same state, has 21.94 of ash and 2.53 of nitrogen. One from Connecticut with 45.31 of ash has 1.92 of nitrogen, while another, with but 3.98 of ash, has 1.48 of nitrogen. Sulphur is always present, sometimes in sufficient quantity to be utilized. It and nitrogen are original constituents and are not due to the transported matter.

Study of ash in peat affords some insight into the conditions prevailing during growth. The mineral content may be original, that is, derived from the plants themselves, or it may have been

149 L. v. Ammon, "Bayerische Braunkohlen," etc., 1911, p. 10.

150 C. A. Davis, "Uses of Peat," pp. 186–203.

introduced by wind or running water. When the deposit has been protected from influx of silt, the ash may be less than 2 per cent. of the dried material; but there is every gradation from that percentage to shale, clay, or sand with merely a trace of vegetable matter. Such variations are commonplace in upland bogs and are illustrated by one in Ohio, recorded by Dachnowski, which had more than five times as much ash on the shallow border as in the deeper portions. Analyses published in European works are too commonly of material from localities where peat is dug, where it is of proved economic value; so that one is liable to suppose that peat with less than 10 per cent. of ash predominates. It would appear, however, that a much poorer grade of peat predominates, except where, in lowland areas, checking of streams at the borders causes dropping of the load or where a dense protecting fringe of plants, like the "cane brakes" of the Mississippi delta, act as filters. The analyses by Stanton in C. A. Davis's work are of samples from many localities in 8 states. Practically all of them were taken from previously unexplored deposits and, being collected according to the official method, they represent the whole thickness. A comparsion of the results shows that the peat from

24 localities has less than 5 per cent. of ash.
74 localities has less than 10 per cent. of ash.
28 localities has less than 15 per cent. of ash.
28 localities has less than 20 per cent. of ash.
28 localities has less than 30 per cent. of ash.
20 localities has less than 40 per cent. of ash.
43 localities has more than 40 per cent. of ash.

The lowest percentage is 1.53, which is less than that of the plants: only 98 samples show less than 10 per cent., while 147 show more, a vast preponderance of worthless material. The analyses, tabulated by Dachnowski,[151] are from 61 localities in Ohio; none is below 3 per cent., 14 are below 10 per cent., while 12 are above 20. When one considers that the samples, in all cases cited, were taken because the peat appeared to be such as might be utilized, it is evident that good fuel peat is only a small part of whole now existing.

[151] A. Dachnowski, "Peat Deposits in Ohio," pp. 366, 367.

The composition of the ash depends on the character of the plants and on that of the rocks over which the streams flow. Potash and soda are usually present, but in small quantity as their salts are soluble and easily removed. Lime, iron, alumina and silica remain. Mills and Rowan[152] have published 27 analyses by Kane and Sullivan, giving composition of ash from Irish peats. In these the lime varies from 12.432 to 45.981 per cent of the ash. Dachnowski gives analyses by J. W. Ames from 12 localities in Ohio, which show the lime varying from 2.210 to 4.529 per cent. of the ash. When one considers the notable quantity of certain conifers in peats, the low percentage of lime is a little perplexing; in most good peats it is only a fraction of one per cent. of the dried peat.

The action of various solvents upon peat was studied long ago by several chemists. Hunefeld[153] examined some loaf-like masses found in a peat bog near Borreby in Sweden. The proximate composition of the material was: Resin, 16.8; resinous matter like asphaltum, 40.0; wax, 2.2; coaly matter, with traces of humus, 38.0; oxide of iron with gypsum, 3.0. The material was supposed by him to be changed bread, which had been buried for about 800 years; but Berzelius objected that one cannot conceive how the constituents of bread could give a substance with this composition. Hunefeld studied numerous peats, treating them with alcohol and ether and obtaining 4 to 5 per cent. of resinous matter. There seems to be every reason to believe that his original work was correct and that he showed that resins, wax and asphaltum exist in peat, where there was no possibility that they were introduced from any external source.

Popular dread lest the draining of Haarlem lake might cause serious injury to the public health led Mulder[154] to examine the dense and the less dense peats separately, but by the same method. The peat was first boiled in water, which afterward was drained off, and the washed peat was dried and treated with boiling alcohol.

152 E. J. Mills and F. J. Rowan, "Fuels," etc., p. 16.

153 Hunefeld, "Nachtragliche Bemerkung über das Brod in Torfmoore," *Journ. f. pr. Chemie,* Jahrg. 1838, Bd. III., pp. 456–460.

154 G. J. Mulder, "Untersuchung über die Harze des Torfs," *Journ. f. pr. Chemie,* Vol. XIX., 1840, pp. 444–453.

When exhaustion was complete, the peat was dried and treated with Steinöl. He obtained four resins, three of which are soluble in hot alcohol, but the fourth is soluble only in the Steinöl. These are from the denser peat. Analyses of the resins obtained from the less dense peats show that they are not the same, though closely related. The quantity of resinous material seems to be greater in the lower part of a deposit; and Mulder believed that it was formed during the process of Vertorfung and not derived from the plants directly.

Smith[155] utilized solvents in the study of some peats from Scotland. In his memoir, he summarizes the results obtained by Hunefeld, Reinsch, Mulder and Jacobsen. He treated his peats with naphtha and alcohol and obtained, as the result of several experiments, 6 per cent. of a solid resin, black and with waxy fracture. This material has: Carbon, 73.39 to 73.55; hydrogen, 10.78 to 10.49; oxygen, not given. Smith says that such wax can be obtained from peat by distillation, but the method of solution secures the crude product as it exists in the peat. He cannot accept the suggestion that the resinous material is due to chemical change but maintains that it must be traced to the original plants themselves; the increase in proportion downwards is due to the waste of more easily decomposed materials while the resistant resins remain unchanged; but in a more advanced stage of chemical action, the resins themselves are attacked and are removed in solution.

In considering these experiments and others of similar character, one cannot determine how much is resin and how much is paraffin material. Graefe's method of treating with benzol gives an approximate determination of the waxes. Von Ammon states that the Schieferkohle of Grossweil has 3.73 per cent. of material soluble in benzol; Kraemer and Spilker[156] examined a considerable number of peats, treating them with benzol and in some cases with toluol. They obtained from 3 to 8 per cent. of wax, the quantity in Hochmoors being less than in other types.

155 R. Angus Smith, "A Study of Peat, Part I.," *Mem. Manch. Lit. Phil. Soc.*, III., Vol. V., 1876, pp. 303–331.

156 G. Kraemer und A. Spilker, "Das Algenwachs und sein Zusammenhang mit dem Erdöl," *Ber. d. Chem. Gesell.*, 1912, Bd. 1, p. 1213.

It is wholly certain that the paraffins are present and that one is not compelled to go outside of the original plants to find a source for these or for the resins. The abundance of conifers leaves no doubt as to one source of the resins and waxes and these are characteristic of swamp plants. They are alike resistant to chemical change. The mode of occurrence of the New Zealand Kauri gum affords the necessary illustration for the resins. Penrose[157] states that this gum, a true resin, is a secretion of the *Agatha australis*, now living within an extensive area in New Zealand. The resin accumulates in large quantity on all parts of the tree and the bark, which peels off and is heaped on the ground, is saturated with it. The fresh exudations are unimportant commercially and the supply is obtained from the buried or "fossil" gum. This is found in regions now covered by the Kauri tree, in others whence the trees have been removed as well as in some where the only evidence of former forests is the presence of buried roots and other portions of the trees. At times, the Kauri forests have disappeared and have been replaced by those of other trees, the only proof of a former forest being the gum and the roots. That the antiquity of early Kauri forests is very great appears certain, for there are trees in the newer forests, which are supposed to be not less than 1,000 years old. At some localities, the gum is found in successive layers, separated by clays or sands, evidence of forests destroyed one after the other. The Senegal copal occurs under similar conditions. In many cases the resin-filled portions of the trees have been preserved, though all others have disappeared.

Distillation Products from Peat.—Lampadius published in 1839 the results of his investigation of products obtained from peat by distillation at and above the "cracking point." The experiments have been repeated many times and with similar general results. Two recent studies will suffice here. The Ziegler[158] process of producing coke from peat with saving of the by-products, has been tested on a commercial scale at some places in Germany. About 33

[157] R. A. F. Penrose, Jr., "Kauri Gum Mining in New Zealand," *Journ. of Geol.*, Vol. XX., 1912, pp. 38–44.

[158] C. A. Davis, "The Uses of Peat," U. S. Bureau of Mines, Bull. 16, 1911, pp. 128–142.

per cent. of good coke, containing 90 per cent. of carbon, is obtained from high-grade peat; though hard and compact, it retains the peat-structure. The tar, a mixture of the more readily condensed hydrocarbon compounds, rarely exceeds 4.5 per cent. of the dried peat, varies much in quantity and is a black viscous liquid. Subjected to fractional distillation, it yields, after separation of water, ammonia, light and heavy oils, paraffin wax, creosote and asphalt. The crude oils are said to be identical with those of petroleum in properties and appearance. The character of the tar water, containing lighter or less readily condensed compounds, depends in part on the character of the peat; the fibrous, less decomposed peats yield more methyl alcohol and acetic acid with less ammonia than those which are darker, thoroughly decomposed and structureless, which contain more combined nitrogen. This tar water contains ammonium salts, acetic and other acids as well as methyl alcohol.

The permanent gases vary with the character of the peat, the quantity of water and the temperature at which the coking is done, there being in every case a considerable proportion of air. The less decomposed peat gives the greatest quantity and the poorest quality. The variability in composition appears from two analyses, the first being from the Ziegler plant at Oldenburg and the other from that at Beuerberg; the percentages are in volumes;

	I.	II.
Carbon dioxide	27.4	15.5
Oxygen	2.2	1.1
Nitrogen	22.5	21.9
Carbon monoxide	8.6	20.4
Carburetted hydrogen	14.8	12.4
C_nH_m	1.0	
Hydrogen	23.6	28.6

The gas burns with a feebly luminous flame. Von Ammon[159] has published results obtained during destructive distillation of Schieferkohle from Grossweil, which is a well-decomposed peat with 60.59 of carbon. Two samples, each weighing one kilogramme, were tested, one retaining the woody structure, the second resembling earthy brown coal. The results are very different from those ob-

[159] L. v. Ammon, "Bayerische Braunkohlen," etc., p. 10.

tained by the Ziegler process. The coke is 23 to 24 per cent., the watery constituents vary little from 63 but the tar is from 1.24 in the earthy to 2.87 in the woody material. The earthy coal yielded 105.63 liters of gas whereas the woody material yielded only 97.55. The composition of the gas is

	I.	II.
Carbon dioxide	38.59	50.86
Carbon monoxide	16.80	10.60
Hydrogen	18.90	15.90
Carburetted hydrogen	0.60	1.10
C_nH_m	2.10	2.10
Oxygen	0.60	0.30
Nitrogen	22.60	17.70
Sulph. hydrogen	0.21	0.74

The tar-water of number I., the ligneous type, is acid, that of the other is alkaline. The amorphous, more changed material has less acetic acid and more nitrogen combined as ammonia, but the gas shows great increase in carbon dioxide with decrease of carbon monoxide. The results may not be wholly comparable, since the lignitic, woody material may contain some constituents in greater proportion than found in the amorphous peat; the former is coniferous wood while the latter was formed in great degree from plants of wholly different type.

Summary.—Before proceeding to consideration of the Tertiary coals, it is well to summarize the facts recorded in the preceding pages.

1. The area of Quaternary and Recent peat deposits is apparently greater than that on which carbon deposits were laid down during any preceding period of similar duration; yet it is but a small part of the earth's surface, for there are vast spaces on which no peat has formed since the Quaternary began, though much of the peatless regions has been forested.

2. Peat bogs vary in size from a few square feet to thousands of square miles. The smaller deposits are due to filling of pools, ponds or lakes by plant invasion, while the more extensive deposits, those on coastal or broad rivers plains, originated, certainly in some, probably in most cases, in small, isolated bogs, which became united

by transgression. These, though continuous superficially, are not strictly contemporaneous throughout. The buried deposits of Holland-Belgium-France are continuous with living bogs on the mainland; but the buried peat, in greatest part, is older than that now exposed, as evidently the marsh crept gradually inland during the subsidence. In like manner, the great deposits formed on plains show notable variation in thickness as well as in composition. The vast peat-covered plains of Alaska and Siberia have a contemporaneous top layer, but the underlying portions of the deposits are probably very far from being strictly contemporaneous.

3. The condition prerequisite to formation of peat is an abundant supply of moisture with sluggish drainage; this does not mean that alternating wet and dry seasons are necessarily preventive. If the supply of moisture suffice to keep the main mass moist, the loss during the dry season is more than made good by growth during the wet season, as shown by some tropical swamps. This condition of moisture depends greatly upon the topography, which determines the character and extent of drainage. Temperature is important as affecting rapidity of growth. In Spitzbergen, 78 degrees, North Latitude, peat covers considerable areas but the deposits are very thin, for the season of growth is brief and the temperature is always low. But the growth is much greater in the Alaska region to beyond the Yukon, where the plane of perpetual frost is within 6 to 14 inches from the surface. The atmospheric temperature during the summer is higher and the winter temperature is lower than in Spitzbergen as the climate is continental, not insular. In the cold regions, decomposition is less advanced than in lower latitudes and the accumulation is of vegetable matter rather than of peat, properly so-called. In the tropical areas, where the topography permits proper moisture conditions, it is evident that prolonged high temperature in no wise prevents accumulation but rather encourages it by favoring rapidity and density of vegetable growth. Koorders, Molengraaff, Harrison, Kuntze and others have described the vast deposits in tropical East Indies and South America. Harper, Hilgard, Lyell and others have described subtropical peat deposits in the United States, while many observers have written about the

temperate zone peats of North America and Europe as well as about those of the arctic and sub-arctic areas. In North America, the passage from subtropical peats of Florida to those of the subarctic areas is gradual; the plant-life changes, but the peat varies little in character. The fact is certain that in the tropics as in the temperates, peat accumulates where the necessary conditions exist and that it does not accumulate in either when those conditions are wanting.

4. Peat may be derived from any land plant, but ordinarily the flora contains many types. The constituent plants vary at the several horizons in a deposit, but for the most part the peat does not consist of any one plant or class of plants. Occasionally a layer consists of remains of a single species, but the occurrence is comparatively rare. The peat-making forms are not the same at all localities. In northern Europe, certain mosses, chiefly *Sphagnum,* are the important constituents in the upper layers, so also in some parts of North America; but there are considerable areas in both regions where mosses are either wanting or are wholly unimportant. Sedges have been the efficient peat-producers in much of the north temperate, even at some tropical and subtropical localities. But there is no limitation; conifers, palms, deciduous trees, mosses, sedges, in a word, any water-loving plant or any plant preferring a slightly acid soil will yield peat under similar conditions; the soft parts become a pulp but the harder parts change more slowly. More than 100 years ago, Al. Brongniart called attention to peat in Holland composed of leaves of conifers and Reinsch, almost 75 years ago, observed similar peat in Germany; the formation of peat from offal of oaks and conifers is a familiar phenomenon in the Rocky Mountain region.

In Tierra del Fuego, where conditions are subarctic, the chief peat producer, according to Darwin, is a sedgelike plant, *Astelia pumata;* in the Falkland islands, every plant is a peat-maker while at Chiloe, *Astelia pumata* and *Donatia magellanica* make up the mass of the peat. The Nile Sudd consists chiefly of sedges and grasses; in Florida, not only conifers of various types but also grasses and sedges contribute, and even the hyacinth has become important. But they all give peat; the sedge-conifer-moss peat of Germany is almost

the same in composition as the peat from Sumatra and other islands within the tropical regions. The differences in composition of peats from these widely separated localities are little greater than those observed in the several benches of any thick deposit.

5. The felted structure of the peat is not due to any special character of the plants, for it is present in forest litter. The extent of chemical and physical change increases downward in a deposit. At the top of a growing bog, one finds living plants, but within two or three inches, the mass consists of dead material, slightly changed in color but with small increase in percentage of carbon. Lower down, the organic structure becomes less and less distinct and, at length, the whole mass is, to the unaided eye, merely a pulp, in which are embedded fragments of wood and occasional leaves. The condition is described by both Darwin and Thomson for southern latitudes. The former, in writing of Tierra del Fuego, says that *Astelia pumata* constantly produces new leaves on the growing stem, while the older ones decay. Traced downward into the peat, the old leaves can be seen in all stages of decomposition until the whole has been blended into a confused mass. Thomson says of the Falkland peat that roots of *Empetrum, Myrtus, Caltha* and sedges can be traced downward for several feet, but finally all structure is obliterated and the whole is reduced to an amorphous, structureless mass. Examined under a glass, this pulp proves to consist mostly of plant remains, fragmentary and irregular in form. The unequal action of decomposing agencies causes this peculiarity of form, which might suggest to some that the plant remains had been subjected to attrition during transport by running water. But the material is of *in situ* origin, and all stages of change are distinct.

The several parts of plants are affected differently and not all plants are affected alike. *Hypnum* appears to be especially resistant, for layers of the almost unchanged moss have been found underlying a considerable thickness of pulpy material. The soft parts of plants are reduced quickly and the wood of most deciduous trees is reduced but little less rapidly. The wood of oak and conifers remains unaffected for long periods, practically the only apparent change being increase in hardness. The bark of nearly all trees

persists even after destruction of the other portions, so that the flattened bark becomes, as it were, an imprint on the pulp.

6. The stages of growth in peat deposits depend very largely on the original topography of the area. In the filling of water-basins, the first stage is formation of mud on the bottom. This may be calcareous, formed by *Chara* and mollusks, and may hold remains of water animals, pollen, spores, freshwater algæ and vegetable remains of other sorts, floated in by streams or blown in by the wind. If streams carry detritus and the water have low calcareous content, the bottom is covered eventually by fine silt with similar organic content; but if the pond be free from influx of detritus and calcium salts, the first deposit is a mud consisting of remains of aquatic animals, freshwater algæ with spores and pollen blown in by the wind. This is the Lebertorf stage, the Sapropel stage of Potonié. This material, in some cases, increases with great rapidity, and the water, at length, becomes so shallow that certain types of aquatic plants take root and the formation of normal peat begins; first, the plants rooting under several feet of water; then reeds encroach and the rushes and sedges advance to form a floating cover, on which shrubs and even trees take root along with ferns and, in many localities, eventually *Sphagnum*. The trees advance, conifers first, to be followed by deciduous forms of the forest type when the surface becomes dry to a depth of a foot or more. Throughout, one finds abundance of spores and pollen grains, and occasionally a lens of Lebertorf occurs, marking the site of a pool or pond in the growing mass. This, in a general way, is the succession as worked out by the early observers and confirmed by all students during the last third of a century.

The succession may differ somewhat in deposits formed on plains bordering great rivers or on coastal areas. These begin frequently, perhaps generally, in small, shallow ponds, caused by local obstruction of drainage and expanded by transgression, which led to union of many small deposits. The Lebertorf stage could exist in the original small spaces but not in the newer portions formed during transgression, except where local ponds originated in the peat.

7. The accumulation of peat has been continuous in few locali-

ties; even small deposits show pauses like those which characterize those of greater extent. Many times a cyclical order is distinct and the deposit is divided into benches. The process was interrupted again and again, so that the surface became dry enough for growth of trees, not merely of conifers but, in some cases, even of deciduous trees of forest type. Sometimes such pauses were of long duration as is shown by the age of the trees. The forest growth was frequently very dense, for the peat is loaded with stumps and broken stems. A considerable proportion of the trees were overturned, perhaps by the wind, and sank undecayed into the soft pulp. The moister conditions returned, the trees were drowned and peat growth was resumed. This succession may be repeated several times in a single deposit.

The benches may pass gradually, the one into the other, or they may be defined sharply by partings. At times the parting consists of Torffaserkohle or mineral charcoal, mingled with extremely fine mineral matter, the residuum on the surface of peat long exposed to oxidation. Such partings mark a period of dryness without invasion by forest, during which the peat wasted. But partings of clay, sand or marl mark invasion by water carrying detritus. After a period, long or short, the surface is again covered with shallow water and peat making is resumed, the parting serving as mur for the new accumulation. The parting of Torffaserkohle and ash may be continuous with the thick parting of transported material, so that when peat making has been resumed over the latter, the process would extend over the thin parting of wasted peat. It is important to bear in mind that the thin parting is more than equivalent in length of time to the thick parting. The new peat, expanding by transgression, required a period for advance; the peat underlying the parting of transported material may be strictly contemporaneous throughout, except that the upper part is represented by the thin parting. A thick cover of detrital matter may bring accumulation finally to a close in one portion of an area while growth continues in another. Sand dunes in some localities within the United States have covered bogs of small size so that no farther increase was possible; but in the Baltic region, as shown by German and Scandinavian geologists,

dunes have covered great portions of the peat area, while other great portions have remained uncovered and in continuous growth.

8. Expansion of peat deposits by transgression has been observed in all parts of the world. Trees, still standing but killed by advancing marshes, have been described by several writers in the United States, and the process of covering the stems has been made clear in preceding pages by citations from Scottish authors. In many deposits of wide extent, the fact of transgression becomes evident only after removal of the peat for fuel or during reclamation. The stumps of the invaded forest are laid bare, their roots still fixed in the mur of the deposit, while their broken and shattered trunks are prostrate in the peat, which accumulated around the trees and destroyed them by preventing aeration of the roots. Many of these great deposits have no trees rooted in the mur in some portions, while those are abundant in other portions. The stumpless spaces mark the places where the bog originated; those with stumps and prostrate stems mark expansion by transgression on the forest area. These features are characteristic of peat deposits in the British Isles, the Netherlands, France, Germany, Sweden as well as of those East Indian swamps which have been reclaimed for agricultural purposes.

9. The effect of pressure on peat is to render it so similar physically to brown coal that the contrast with normal peat is very great. Forchhammer, Jentzsch, Nilson, Lesquereux, Goeppert and Schreiber have written in detail respecting this matter and incidental observations are to be found in writings by other authors. Even the long-continued pressure of peat itself in a deep deposit has much the same effect on the lowest layers.

10. Peat contains introduced materials of various kinds. Logs and stumps are not of these; they are merely the more resistant parts of peat-making plants, embedded in pulp from less resistant portions. Fragments of rock, sometimes angular, sometimes water-worn, have been reported from a few localities. The comparative infrequency of references may indicate rarity of occurrence, localization within the peat or the indifference of observers. The facts available are so few that any suggestion as to the origin of these fragments would be worthless. Often, there is much silt; at times, one

finds pockets of sand or clay, even of freshwater limestone. The limestone cannot be regarded as extraneous, for in all probability it was formed *sur place* in ponds within the swamp; but the other materials are of foreign origin and indicate more or less frequent flooding by detritus-laden water. In considerable areas, the quantity is so great as to render the peat worthless; in others the material is localized, as in bogs of lake or pond origin, where the peat on the borders is commercially worthless, while midway in the basin it is almost free from mineral admixture. The several benches of a peat deposit often differ notably in mineral-content, showing variations in conditions during formation. Bones of mammals, shells of freshwater mollusks, remains of beetles and other insects are of common occurrence. Peat deposits have yielded the best specimens of Pleistocene mammalia; domestic cattle are often mired in swamps and whole troops of armed men have perished in Scottish swamps during flight after battle.

11. The floor or mur of peat deposits may consist of any mineral material not injurious to plant life. Ordinarily, in swamps originating in ponds, it is composed of more or less nearly impervious stuff, clay, lake marl or Lebertorf mud. Where a deposit has increased by transgression, the mur may be shale or even sand; but in the latter case the immediate floor is apparently the cover of forest offal, the underlying sand having been rendered more or less nearly impervious by humic acid derived from the organic cover. The characteristic feature of the mur is the presence of roots belonging to peat-making plants. In original localities, where peat was formed in open areas, the roots are those of reeds, rushes water-lillies, etc.—the Rohrrichtboden of German writers being a familiar condition. Where the deposit originated in forests or encroached upon them, one finds in the mur a tangled mass of roots, oaks, conifers, alders, birches and other plants, from which the stems very commonly pass into the peat. These stems rarely extend beyond the peat cover and they are broken off at practically the same level. Where the deposit consists of several benches, each becomes in turn a mur for the next, and roots are distributed in the peat-mur as in the original clay or other mur; in each bench the stumps are cut off at or below the top of the peat.

It is seemingly probable that the pause at the close of the bench-formation was long enough to permit complete decay of exposed parts of the stems. Usually, however, the decay was complete before the end of the peat-forming period and one generally finds the upper part of the bench continuous over the tops of the stumps. The durability of stumps and of some woods is remarkable even when they are exposed, and it is much greater when they are buried in peat or in loose material containing much moisture. But decay of the wood is much more rapid than that of the bark; a stem may become hollow and the space may be filled with silt or sand holding leaves or remains of small animals, as Lesquereux, De la Beche and Potonié have shown.

12. The roof or toit of a peat deposit may be as variable as the floor. As in the latter one finds usually a gradual passage from the rock to the peat, giving a faux-mur, so on top one finds similarly a gradual passage from peat to rock, a veritable faux-toit. In this, one recognizes frequently roots, stumps and prostrate stems, remains of the forest which covered the peat. But the forest was not always present; the deposit was buried before the cycle had been completed, so that one finds, mingled with the silt or sand, leaves only of upland vegetation. The roof may be of freshwater, marine or æolian origin, it may be sand, clay, marl or limestone; the calcareous beds accumulate slowly, the others slowly or rapidly. Erect trees, rooted, are found in the roof material, but unlike those in the peat, they are not all broken off at the same height. Where engulfing material is æolian sand not deposited continuously, the trees may adjust themselves to the conditions and a long period may elapse before their death, so that the buried forest may remain in normal position and the erect trees may penetrate a notable thickness of rock, as in the Baltic provinces. When the material has been transported by running water, the accumulation may be less rapid, but enough so to kill the trees by rendering the cover too wet. The erect stems may be of any height, from mere stumps to a score or more feet and they may be surrounded by rocks of various kinds, sands or clays, in mass or in alternating layers.

Under the term "roof" may be comprehended all rocks between

one peat horizon and the next. Very often one finds in this interval alternation of land, freshwater and marine conditions. The immediate roof may be clay succeeded by sand, both of freshwater origin, but on these may rest sand or marl with shells of familiar marine mollusks. The sands frequently contain transported remains of plants, in some cases trunks of trees, prostrate, inclined or even approaching the vertical and accompanied at times by bones of various mammals, with land, freshwater or brackish water shells. The plant remains usually differ from those in the peat, and they appear to have come from undermined banks of rivers. An interesting and by no means uncommon feature is the occurrence of "soils of vegetation," bearing remains of forest growth, there being an accumulation of forest offal about and between the stumps. These mark exposed surfaces on which trees grew but where swampy, peat-forming conditions did not prevail. Erect as well as prostrate trunks are present, all enveloped by the mass of sand or clay which buried the old soil.

13. All areas in which peat accumulates have imperfect drainage; the streams are usually sluggish and are easily diverted. The peat, at times, encroaches on the channelways and eventually fills them. This condition is recognized readily when the section is exposed in excavations for reclamation canals, for the silt or sand forms a "roll" on the bottom, narrowing upward and covered by peat. Sometimes a new channel is formed during a flood and the sand-laden water tears away the peat, sometimes to the bottom, giving a "roll" in the roof, which narrows downward. Similar conditions are not rare in interval rocks between peat horizons, buried channelways being of frequent occurrence. This contemporaneous erosion marks the existence of land surfaces.

14. Plants growing on peat show great adaptability to changing conditions. Birch requires that the roots have free access to air, but C. A. Davis states that he has seen birch making thrifty growth, where the roots had been covered during two growing seasons by a foot of water. Shaler described the habits of *Taxodium distichum,* the familiar cypress of our southern swamps. Where the region is dry, the plant shows no peculiarity of root structure; but

when it grows in a swamp, where the roots are in the saturated peat, covered with water, it puts forth the curious "knees," which project beyond the water surface and provide means for aeration. If the water-level be changed abruptly, so that the knees are submerged, the tree dies, as appears in the New Madrid area, where during the earthquake of 1811, the land sank and the swampy area became a lake. *Nyssa* is provided with an equivalent protection for aeration. Conifers are found far out on the wet sedge-mat, which floats on the surface of a lake; but they grow slowly amid the untoward conditions and usually are overturned by the wind before attaining great size, as their roots are radial and very near the surface. Capp's observations respecting conditions in the White river district of Alaska are thoroughly illustrative. Peat as a soil is not repugnant to plants. The acid character of new peat is offensive to most of our deciduous trees and to many other plants; but many others, among them majestic trees both conifer and deciduous, thrive best on the damp acid material. When a bog ceases to grow, the thin upper layer becomes freed in considerable measure from the acid and the moisture; usually it is occupied quickly by the ordinary forest trees of the region, though the saturated peat may be only a foot below. The roots of these trees are radial, creeping near the surface.

15. Peat, deprived of moisture and exposed to the air, quickly undergoes change. The soluble cementing material becomes insoluble, or is removed, the mass becomes pulverulent and is apt to be swept away by the wind. The vast reclamation works, which have converted swamp areas into agricultural land, have exhibited the changes on a grand scale. The natural conclusion seemed to be that peat has been formed only to waste away. But this is an error. Peat has been formed to be preserved. Peat deposits in Scandinavia, Germany and Great Britain have existed since the Glacial period and in not a few localities they are still growing. But the growth has been interrupted many times and for considerable periods; the surface was exposed, but not long. Under ordinary conditions, shrubs and trees advance as the peat surface dries and the Waldmoor or forested bog is protected from waste. Under

other conditions, the bog may be covered by mineral materials, as on the lowland of Holland, Belgium and France, and waste by oxidation is prevented. By one method or the other the peat is preserved indefinitely: by the former method, the continued increase of peat is assured in most cases, as the forested surface again becomes marshy and peat production is resumed, to end again in a forest. This cycle has been reported again and again from peat bogs of northern Europe. The thickness of a deposit depends, other things being equal, upon the period of growth; the thickest deposits reported are those in Alaska and in tropical and subtropical regions; in those regions climatal changes have been comparatively small since the Quaternary began.

16. The composition of peat depends ordinarily upon its age, that at the bottom of a deposit not only approaches complete disintegration, so that to the unaided eye it shows no trace of organic structure, but it also is far advanced in carbon-enrichment. Yet peat from neighboring localities, where conditions seem to have been similar, may show great dissimilarity in composition; one finds strange contrasts even in the benches of a single deposit, for some may be far advanced while others consist of almost unchanged plants. This study is not concerned with the processes involved in conversion of vegetable matter, so that one must be content with the statement that some benches were buried when those processes had been checked at an early stage and that apparently no progress has been made since burial. The carbon in peat may vary from little more than 40 per cent. in the topmost layer to 49 in the next—the first used for fuel—and to 64 in the bottom portions. But in bogs where the surface growth has ceased or has been unimportant for a long period, the part immediately below the surface may have 58 to 60 per cent. Oxygen shows similar variation; there being 36 to 40 per cent. in the highest part used for fuel while the oldest, densest portions may have only 26 or 27 per cent. The ordinary fuel peat has from 57 to 64 per cent. of carbon. Density is not evidence of advanced change; the dense, hard, black Schieferkohle of Utznach, compressed by the heavy cover, has 56 per cent. of carbon and 36 of oxygen.

The ash is extremely variable even in a single deposit. Only a small proportion of the peaty material on the earth's surface is good enough for fuel and a great part of that now forming is little better than carbonaceous shale, with 25 to 50 or more per cent. of mineral matters. At times peat is found with less ash than should be expected, less than that contained in the original plants. Solution has made possible the removal; potash and soda are usually present, but in small quantity, the greater part having been removed. Lime, iron and alumina are always present, though in exceedingly variable proportions, this being due perhaps to the character of the drainage area—but this suggestion is not always satisfactory.

At many localities, the organic acids in solution have become a cementing material, more or less disseminated throughout the structureless mass, dopplerite in peat, Carbohumin in Schieferkohle. In peat, it is gelatinous, but after the water has been removed it is hard and insoluble. It has reached the latter condition in Schieferkohle.

Resins, waxes and paraffins exist in peat, from which they can be extracted by solvents. They have been derived directly from the plants; there is no reason to believe that they were formed during the conversion into peat or that they were introduced from an external source.

The Tertiary Coals.

Tertiary coals, of the ordinary types, are termed Braunkohle in Germany and Austria but in France and English-speaking countries they are known as lignite. The passage from peat to brown coal is extremely gradual and occasionally, as indicated on preceding pages, determination of the relations is merely a matter of personal equation. In Europe generally the complex group known as brown coal has abundant points of similarity distinguishing it from the Palæozoic or "stone" coals, so that, as Mesozoic coals are comparatively unimportant, the effort there has been to ascertain why brown coal and stone coal are so unlike and to discover reasons why the former could not be converted into the latter. But in North America the condition is wholly different, for coals of all types from wood-like lignite to bituminous, even to anthracite occur at

times within a single district, in a single bed or even within the limits of a single estate. The passage from one type to the other is so gradual that chemists and geologists of North America have labored to discover some means of distinguishing them. The problem is no longer one of merely abstract or scientific interest; it is of the utmost practical importance, since within a vast area the only source of supply is in the Tertiary and Upper Cretaceous deposits. The effort is to determine distinctions which will be available for both the seller and the purchaser of fuel.

In most works, the characteristics of brown coals are given definitively. Though in mass the color may be black, yet the powdered material has a brown tint; the content of water is considerable and air-dried specimens retain 10 per cent. or even much more, so that brown coals have been termed hydrous; jointing or cleat is wanting or at best ill-defined; the water in air-drying escapes through shrinkage cracks or along bedding planes and the coal falls into small fragments; brown coals do not coke; solution of caustic potash attacks brown coal and acquires a reddish or brownish tint; brown coals contain more carbon than peat but notably less than the stone coals.

These features are characteristic of brown coals in general but they are not wholly distinctive. Some brown coals yield a black powder and some Carboniferous coals give a brownish powder; many Carboniferous coals retain more than 10 per cent. of water and there are Tertiary coals with very much less; there are Tertiary coals with very distinct cleat while there are Carboniferous coals in which cleat is very indefinite; there are Carboniferous coals in extensive areas whose included water escapes along the bedding planes and the coal breaks first into slabs and then into small fragments; a very great proportion of Carboniferous coals do not cake while there are Tertiary coals which yield good coke; caustic potash solution attacks many Carboniferous coals; the carbon-content is not definite. In fact, the passage from brown to stone coal is as gradual, chemically, as that from the growing layer of peat to brown coal.

A proper examination of this matter will be in place only after study of the Palæozoic coals. For present purposes, the classifica-

tion by Hoffmann[160] must answer. He recognized a gradual change in the chemical and physical character of the upper Mesozoic coals from east to west within the Bow and Belly river region of western Canada. In the eastern strip of that district, the fuels have all the characteristics of lignite (brown coal); those of the middle strip are intermediate between lignites and true coals, the latter being found in the western strip; while in the mountains, farther west, anthracite occurs. All belong to the same general horizon in the Upper Cretaceous. Reasoning from the series of analyses which he had made, he grouped the fuels into lignites, lignitic coals and coals. Lignites are fuels which, on exposure to the air, tend more or less to disintegrate and to fall to pieces; they all communicate a deep brownish red to boiling solution of caustic potash and contain 10 to 15 per cent. of hygroscopic water, sometimes even more; they do not yield a coherent coke. Lignitic coals show much less tendency to disintegration, give less deep coloration to the potash solution, have less hygroscopic water, 5 to 9 per cent., and are practically non-caking. Coals are hard and firm, give only slight coloration to the solution of caustic potash and yield a non-coherent coke by slow coking, but a firm coke by fast coking. In the relations of carbon, hydrogen and oxygen they closely resemble some British non-coking coals. This grouping is very similar to that used by the United States Geological Survey, which is, lignite, subbituminous and bituminous coal.

Coal has been found in all portions of the Tertiary column. Pliocene deposits of some economic importance have been found in Italy, Hungary, Germany, New Zealand and Alaska. The Miocene coals of Hungary, Bohemia, Germany, Bosnia, France, Spitzbergen, Iceland and Greenland as well as those of Trinidad and the adjacent portion of South America are of great extent; coal of this age has been found in Central America and occasionally in North America, but the deposits are apparently unimportant. Oligocene coals are mined extensively in Hungary, Germany and Switzerland, but they have not been recognized definitively in North America ex-

[160] G. C. Hoffmann, "Chemical Contributions to the Geology of Canada," Rep. Prog. Geol. Surv. Canada, 1882–4, Pt. M, pp. 1, 2, 5–8; Ann. Rep. 1888–9, Pt. R, pp. 9–18.

cept in western Canada. Eocene coals are present in Bavaria, Austria and Hungary, but, for the most part, the areas are inconsiderable. Deposits of this age in India, Java, Sumatra and Borneo are well known, while those of western North America are the main source of supply for a vast area.

Classification of Tertiary Coals.—As the Tertiary brown coals have supplied a great part of the fuel consumed in Germany and much of France during more than two centuries, they have been classified to the last degree of detail. Brongniart[161] recognized four types, Lignite jayet, which he thought equivalent to Pechkohle, though it is evident that his reference is to the mineral jet; Lignite friable, la houille limoneuse of Brochant, regarded by him as synonymous with the German Moorkohle; Lignite fibreux, which retains the woody structure; Lignite terreux, bituminöse Holzerde, commonly known as Terre de Cologne, black to blackish brown, with fine-grained earthy fracture, mostly homogeneous, but containing embedded trunks of trees.

Zirkel's[162] grouping utilized the popular names as employed in Germany: Pechkohle, compact, brittle, pitch-black, waxy or greasy luster, conchoidal fracture; approaches stone coal but is structureless; Gemeine Braunkohle, or common brown coal, compact with more or less conchoidal fracture, less hard and brittle than Pechkohle, blackish brown to pitch black, with or without woody structure, passes on one side into Pechkohle and on the other into Moorkohle, a dense mass even in structure, black with bright streaks, is closely related to Erdkohle, or earthy brown coal, which is a friable mass of dust-like more or less loosely consolidated fragments, with dull luster and earthy fracture; Lignit or wood brown coal, in masses showing texture of wood, twigs, flowers, roots, etc.; Bastkohle and Nadelkohle are merely varieties of Lignit; Blätterkohle, Dysodil and Papierkohle are finely laminated; Wachskohle contains 62 per cent. of paraffin.

Zincken[163] presented a somewhat similar classification but in such detail as to exhibit sufficiently the great complexity of the group

161 Al. Brongniart, "Mineralogie," T. 2, pp. 50 ff.

162 F. Zirkel, "Lehrbuch der Petrographie," Bd. I., pp. 390–392.

163 C. Zincken, "Die Physiographie der Braunkohle," pp. 168 ff.

known as brown coal. The terms, for the most part, are those in popular use, showing that the distinction between the several members is notable. (1) Gemeine Braunkohle, in more or less hard masses, with or without trace of woody structure, brown to blackish brown, with bright streak, dull fracture, breaks into irregular angular fragments, is intermediate between Erdkohle and Pechkohle; (2) Erdkohle, earthy brittle, yellowish to dark brown, wholly amorphous, much cleft by drying, alternating bright and dull laminæ, the former more common in the upper part of beds while the denser varieties in the lower part of the bed give a shorter flame. The varieties are very numerous; Schwelkohle, very bituminous, resinous, yields tar, illuminating gas and paraffin; Schmierkohle belongs in the upper part of beds and when damp feels like clay, Colnische umbra is an earthly brown coal utilized as coloring material, Russkohle, earthy, dusty, of irregular occurrence; (3) Lignit, masses of wood, more or less fossilized, passes over into ordinary brown coal, is yellow to dark brown and breaks like wood, may contain patches of Erd-, Pech- and Glanzkohle, some lignits in drying become Pechkohle. It is derived mostly from resinous trees, the stems being flattened by softening and pressure. The varieties are numerous; Bastkohle forming layers or parts of layers, more or less of bark structure belonging to *Pinus, Taxus, Alnus,* etc., Nadelkohle, bundles of tissues of palms with parenchyma removed; (4 and 5) Dysodil or Papierkohle and Blätterkohle, in very thin laminæ; (6) Moorkohle contains abundance of remains of swamp plants as well as compressed woody roots, small stems, etc., usually associated with deposits of lignit and occurs in the lower portion of the bed or fills spaces between the stems; (7) Pechkohle, dense, more or less brittle, rather tender, breaks into sharp angular fragments, black brown to pitch black, dull pitch-like to greasy luster and irregular to conchoidal fracture, passes over to common brown coal on one side or to Glanzkohle on the other; sometimes it occurs in Moorkohle, while at others it includes thin to 5-inch layers of Glanz-, derived from conifer stems pressed flat; (8) Glanzkohle is dense with conchoidal fracture, is blackish with greasy, vitreous or metallic luster; sometimes it forms whole beds but it is often as-

sociated with other types and not rarely one finds laminæ of Glanz- alternating with those of dull coal, giving a banded appearance to the section. This is the hardest variety of brown coal and is derived prevailingly from resinous woods. (9) Gayet or jet, dense, hard but not brittle, richly bituminous.

Von Gümbel[154] was satisfied with a much simpler classification. His subdivisions are Lignit, Pechkohle, typical Braunkohle, which includes all the other varieties of authors. He adds Faserkohle, the same with mineral charcoal or fusain.

Toula's[165] system is as simple as that of v. Gümbel, but quite different in the method of grouping. Glanz- and Pechkohle are varieties of the black coals; Moorkohle in many ways resembles peat; Blätterkohle or Dysodil and Lignit are defined by him as by other writers. All are allied closely to types of materials observed in peat deposits.

The array of terms is formidable, but the condition is less complex than it appears. A bed never consists wholly of any one type; ordinarily several kinds of coal are found in a single bed, where those most in contrast are often found in intimate association. The great variety shows sufficiently well that the term brown coal or lignite is applied to a group of substances differing in mode of occurrence as well as in chemical and physical character, among them some closely allied to peat and others which bear great resemblance to the Palæozoic coals. Owing to the great diversity in conditions, it is necessary to present descriptions of deposits in the order of their age and in some detail, reserving until the close an effort to determine the features which are in common.

The Pliocene Coals.—Descriptive notes respecting the Pliocene coals are comparatively few. Some of the deposits are on the border line between Tertiary and Quaternary, so that the age is indeterminate. Collier[166] discovered an area of this kind near the palisades of the Yukon River in Alaska. Bluffs of silt and gravel, 150 feet high, line the river and contain so many bones of large

164 C. W. v. Gümbel, "Beiträge," etc., pp. 139 ff.

165 F. Toula, "Die Steinkohlen," Wien, 1888, p. 18.

166 A. J. Collier, "The Coal Resources of the Yukon, Alaska," U. S. Geol. Survey, Bull. 218, 1903, pp. 43, 44.

mammals that the deposit is known as the "bone yard." Recent land and freshwater shells as well as cones of a *Picea*, like those of the Yukon spruces are associated with them. These silts and gravels enclose beds of vegetable matter, one more than 20 feet thick, in varied stages of conversion, from pliable wood to brittle brown lignite. As a whole the similarity to recent peat is very close. Collier's description suggests that the deposits mark sites of flood-plain swamps, more or less forested and subject to overflows by floods which, like those of this day, left behind sands as well as the trees from undermined sandy banks of the river.

Haast[167] saw at several localities in New Zealand, deposits of lignite or "lignitic brown coal," belonging to late Tertiary or in some cases to early Quaternary. At one, the bed is 3 feet 2 inches thick and the coal retains the woody structure; at another, he measured 14 feet of brown coal while at a third, the section shows numerous beds, 2 inches to 5 feet thick, separated by fireclays, shales and porphyritic tufas. Some lignites are distinctly ancient peat bogs while others are composed chiefly of timber. Hutton[168] recognized undoubted Pliocene lignites at many places in southern New Zealand, especially around the margins of old lake basins and in river valleys, which existed prior to the great depression of the newer Pliocene. Occasionally, one finds well-preserved stems and usually the vegetable origin of the material is distinct to the unaided eye; but, at times, the mass is compact, brown, structureless and cannot be distinguished from brown coal. The thickness at one place is 30 feet; but "like all lignite beds" the deposits are local and not connected.

Hantken[169] states that in Hungary the Pliocene frequently contains lignite and that the deposits are freshwater, holding *Unio* and *Paludina*. The beds are broken by irregular partings and vary much, even abruptly, in thickness and quality. One bed has 8 benches of brown coal, in all 3.5 meters, with 7 partings of clay, the whole thickness being 6.36 meters. The lower benches are

[167] J. Haast, Rep. New Zealand Geol. Survey for 1873–4, pp. 14, 15.

[168] F. W. Hutton, "Geology of Otago," Dunedin, 1875, pp. 96, 98.

[169] M. Hantken, "Die Kohlenflötze und der Kohlenbergbau in den Ländern der ungarischen Kröne," Budapest, 1878, pp. 341, 343, 352, 353.

harder than the upper ones. At another place, the bed consists of brown coal, 7.5 meters, clay, 0.25 meter, brown coal, 0.25 meter. The lower bench is harder and better than the upper one, which is crowded with stems of *Sequoia langsdorffii.* The roof is clay, with impressions of plants.

Von Ammon[170] has described the Gustav mine, near Oettingen a.M. in Bavaria, as yielding Moor- and Mooskohle with included Lignit (bituminöse Holz). This chief bed, underlying upper Pliocene clay, is from 8 to 16 meters thick and is mined in open workings within an area of about 2,000 acres (800 ha). At Schwarzenfeld, the workable coal is but 2.5 meters thick and contains not far from 16 per cent. of wood. In all cases, the observer appears to have been impressed profoundly by the resemblance of these deposits to peat beds, both in structure and in distribution.

Miocene Coals.—Marine conditions prevailed in the present coastal plain along the Atlantic in North America during the Miocene and conditions favoring accumulation of vegetable matter did not exist in the adjacent region, for no coal has been found. But the vegetation was there and swamps were on some of the streams. Berry[171] discovered the remains of a cypress swamp near Richmond, Virginia, associated with the well-known diatomaceous earth of that region. Among the characteristic plants are *Taxodium, Nyssa, Salix, Quercus* and others of types familiar in modern cypress swamps. The conditions for some reason were equally unfavorable elsewhere on the continent, and no coal positively identified as Miocene has been found anywhere in economic quantity except within a petty area in California. There,[172] in the Monte Diablo range, is the bed, which was mined long ago and for many years was the chief source of fuel for steamboats. The bed, as measured by Arnold, is 14 to 16 feet thick and has a dip of about 70 degrees. The coal varies greatly in quality both vertically and horizontally, specimens from some openings being, in composition, very much

[170] L. v. Ammon, "Bayerische Braunkohle," etc., pp. 15–21, 26, 27.

[171] E. W. Berry, "A Miocene Cypress Swamp," *Torreya,* Vol. VIII., 1909, pp. 233–235.

[172] R. Arnold, "Coal in the Monte Diablo Range," U. S. Geol. Survey, Bull. 285, 1906, pp. 223, 224.

like bituminous coal while those from others are lignitic. There is a marked variability in the percentage of ash. In burning, this coal gives off an enormous volume of smoke.

Pardee[173] has recorded brief notes respecting deposits in Montana, which appear to be on the border line between Miocene and Oligocene. They are lenticular and consist of remains of vegetation, which grew on the flats, mingled with silts from the muddy water which frequently flooded the spaces. The coal attains a maximum thickness of 7 feet, is banded, with alternating bright and dull laminæ, has semi-conchoidal fracture, splits along the bedding planes and has two sets of joints, intersecting at right angles. It is usually dense and brittle, but at one mine some of the layers are rather tough and woody. The streak is brownish and the coal tends to slake on exposure. The dip throughout the region is gentle.

The Miocene coal of Greenland was discovered long ago and it has been utilized in a small way. Brown[174] gave numerous sections from one area. The important bed of the region explored by him is on Heer's creek, where it is double, showing coal, 2 feet 6 inches, shale, 1 foot 6 inches, coal, 1 foot. The coal is but slightly coherent, has cubical fracture and breaks down readily on exposure. Retinite is abundant in lumps from mere specks to the size of a marble. Many stems of trees are in the upper bench, but they have been replaced with chert. Somewhat later, Heer[175] described a bed of coal near Discovery Harbor, 25 to 30 feet thick and with extreme dip of 10 degrees. The overlying black shale is rich in plant remains; among which, as in Spitzbergen, conifers hold the first place, ten species having been recognized; with them are eight species of dicotyledons, belonging to families usually well represented in swamp floras, such as birch, elm, waterlilly and other types of similar habit. Heer regards the whole assemblage as indicative of swamp origin for the deposit. The coal falls to pieces readily on exposure;

[173] J. T. Pardee, "Coal in Tertiary Lake Basins of Southwestern Montana," U. S. Geol. Survey, Bull. 531 G, pp. 11–15.

[174] R. Brown, "Geological Notes on the Noorsack Peninsula," etc., *Trans. Geol. Soc. Glasgow*, Vol. V., 1877, pp. 91, 95.

[175] O. Heer, "Notes on Fossil Plants Discovered in Grinnell Land," *Quart. Journ. Geol. Soc.*, Vol. 34, 1878, pp. 68–72.

but the analysis of an air-dried specimen by R. J. Moss as given on p. 563 of the volume just cited, shows for it a composition not far from that of a well-advanced bituminous coal: Water, 2.01; ash, 8.49; carbon, 82.97; hydrogen, 6.15; oxygen and nitrogen, 10.87.

The coal beds of Trinidad,[176] in the West Indies, are part of a deposit originally continuous southward in Venezuela, where it underlies an area of not less than 36,000 square miles. This region lies south from N. L. 10 degrees, where the climate during the Miocene was intensely tropical, as it still is. The newer Parian group has a fauna allied to that of the Miocene and the coal beds are in the lower members, the Caroni and the Moruga. Those of the former, from mere films to 4 feet 6 inches thick, are well shown in the interior where the upper beds, with dip of 15 degrees, are distinctly ligneous, but the lower beds, with dip of 40 to 50 degrees, are, to the naked eye, structureless. No roots were recognized in the underclays. The Moruga beds are not important; frequently they are little better than carbonaceous shale. At two places, roots were seen "rectangular to the bases of the strata." The accompanying rocks in both divisions are chiefly shales, but the Caroni contains a thick sandstone with ripple-marked surfaces.

Returning to the north, important deposits of coal[177] have been opened in the Miocene on Advent Bay. The bed is triple at 60 yards from the crop, showing coal, 1 foot 8 inches, clay, 2 to 4 inches, coal, 1 foot 7 inches, sand, 3 to 5 inches, coal, 1 foot.

In the upper benches the coal is hard, grayish-black, imperfectly laminated and with a somewhat conchoidal fracture. The bottom bench is black, laminated, rather lustrous and tends to be prismatic. Mineral charcoal is present in considerable quantity. In general appearance, coal from the upper benches is mostly splint-like but that from the lowest bench is remarkably like ordinary bituminous coal. Air-dried specimens contain less than 5 per cent. of water. Caustic potash solution attacks the coal throughout and acquires a very in-

[176] G. P. Wall and J. G. Sawkins, "Report on the Geology of Trinidad," London, 1860, pp. 41–50.

[177] J. J. Stevenson, "The Jurassic Coal of Spitzbergen," *Ann. N. Y. Acad. Sci.*, Vol. XII., 1895, pp. 82–95. The assignment of this coal to the Jurassic is an error; Nathorst has shown that it is Miocene.

tense coloration. On the pure coal basis, the upper benches contain almost 10 per cent. more volatile than that from the lowest bench.

The Sutarbrandur of Iceland was described briefly by Jardin.[178] Robert had supposed that these deposits consisted merely of drift-wood, but Jardin recognized that the quantity is too great to admit of that explanation. The beds are numerous, having been seen on all coasts except the southern; they are horizontal and their thickness is from mere films to 12 meters. The material is sometimes compact and free from inorganic admixture, at others, it is fragmentary, mingled with pebbles and dirt while at others still it is almost pulverulent. When compact it consists of alternating dull and bright laminæ. Mouchet's study with the microscope showed that this coal is derived chiefly from conifers.

Geikie[179] states that in the Faeröe Islands coal of Miocene age is associated with dark carbonaceous clays and is more or less lenticular. The formation is 10 to 15 feet thick on the island of Suderöe, where he observed two types of coal; one is bright, with glassy fracture, not soiling the fingers and not unlike some of the Scotch parrot coals; the other is dull, lusterless, soils the fingers and shows vegetable structure. These alternate in the seams but the dull slaty coal is more abundant than the other. Johnstrup, cited by Geikie, held that every lens of glance represents a flattened stem, in which annual rings can be seen. Geikie found this not true of the thinner streaks and threads. The glance coal has 12 to 14 per cent. of water and only 2.5 per cent. of ash; whereas the better quality of the slaty coal has 11 to 17 per cent. of water and 10 per cent. of ash. The conditions resemble those in the Scottish coal fields, which led Geikie to suggest that the coals are due to gradual accumulation of different plants or of different parts of the same plants.

Fournet[180] saw at Sonnaz near Bourget in France a coal bed with this structure: Lignite, 1.30 m.; clay, 0.30 m.; lignite, 0.10 m.; clay, 0.05 m.; lignite with *Planorbis,* 4 m.

[178] E. Jardin, "Note sur le Sutarbrandur d'Islande," *Bull. Soc. Geol. France,* II., Vol. 23, 1866, pp. 456–459.

[179] J. Geikie, "On the Geology of the Faeröe Islands," *Trans. Roy. Soc. Edinb.,* Vol. XXX., 1882, pp. 227–230, 240, 267.

[180] J. Fournet, "Note sur les lignites tertiaires de la Tour-du-Pin (Isère)," *Bull. Soc. Geol. France,* II., Vol. XI., 1854, pp. 763–772.

This bed underlies 52 meters of sand and gravel; at 5 meters below it is a thin streak of lignite resting on white clay, which contains *Helix* and *Planorbis*. At Tour-du-Pin, the partings are marly and the underclay contains laminæ of lignite, which become thicker as the bed is approached. The lignite there is distinctly laminated and is so hard that it can be removed only with picks. The laminæ, completely "bitumenized," show vegetable impressions but no leaves or flattened stems. Near Vion, on the border of Isère, mineral charcoal is abundant between the laminæ and embedded trunks of trees are not rare. Some parts of this deposit are brown, but others are "bitumenized." The constituents are distinct, for Fournet recognized débris of birch, juniper, fir, cherry and walnut, with sedges, rushes, elytra of insects and *Planorbis*. He was impressed by the remarkable resemblance to coal beds; the partings, the passage of the floor into the lignite, the lamination and the abundance of mineral charcoal. One cannot fail to see in Fournet's description an equally close resemblance to peat deposits; land and freshwater mollusks, elytra of insects, all found in the lignite as well as in the underclay, the character of the plants, the structureless mass in which the plant remains and the shells are embedded.

Daubrée[181] published some notes respecting his observation in the Lower Rhine area. Near Soultz-sous-Forets, he found marls with layers of sand. The latter contain bituminous lenses, which near Bechelbronn have 2 per cent. of bitumen with some pyrite. They hold much carburetted hydrogen and disastrous explosions have occurred in the works. Some thin beds of lignite were seen, which have impressions of *Helix, Lymnæa* and *Bulimus*. The same shells were seen at Lobsann, where, above the marls, are freshwater limestones with thin lignites, in all from 5 to 9 meters thick. This limestone yields 10 to 18 per cent. of bitumen and contains gypsum as well as pyrite. It is rich in *Chara,* the individuals being silicified and remarkably well preserved; but other remains of vegetables are in poor condition.

The lignite streaks are very thin and only some millimeters apart, there being alternate layers of lignite and limestone, sometimes 40

181 Daubrée, "Notes sur le gisement du bitume, du lignite et du sel," etc., *Bull. Soc. Geol. France,* II., Vol. VII., 1850, pp. 444–450.

to the meter; but occasionally the lignite is 30 to 60 centimeters thick and is mined. Quartz masses are present in the lignite as well as in the limestone, which, judging from Daubrée's description, are probably of secondary origin. This Lobsann fuel is the lignite bacillaire, the Nadelkohle, which is merely débris of palm trees, from which connective tissue has been removed, leaving the loosened bundles of fibers. This constitutes the greater part of the beds and the arrangement shows that the stems were prostrate. But with this is another fibrous type, much finer and allied to mineral charcoal. Microscopic examination proved that this is derived from coniferous wood; palms and conifers were associated in the forests. Succinite is abundant in this lignite, but the balls are rarely larger than a pea and usually are of pinhead size; he counted 40 droplets in a cubic decimeter. It is most common in beds consisting largely of coniferous débris, the fibers of mineral charcoal being still impregnated with the resin, as appears distinctly under the microscope. This lignite is always laminated, the laminæ being less than one millimeter thick and alternately bright and dull, the latter being the less pure. *Bulimus* and *Planorbis* were obtained from the lignite. This freshwater series of lignites and limestones is succeeded by marine marls, containing *Spatangus, Cerithium, Venericardia* and other forms of similar habit.

Potonié[182] described the great deposit of brown coal near Senftenberg in Niederlausitz. The bed is more than 10 meters thick, and is mined by stripping at several places. The author gives reproductions of two photographs, one being a panorama of the principal excavation, the other showing distribution of erect stumps. As in many recent and Quaternary peat deposits, one finds here several generations of forest, one above the other, embedded in humus material, the only difference being that homogeneous peat has been converted into brown coal. In the floor, as in the roof, are many great erect stumps, those of the former being rooted in the underclay, those of the latter, in the brown coal. Some stumps have a diameter of several meters and the intervals between trees are such

[182] H. Potonié, "Ueber Autochthonie von Carbonkohlen-Flötzen und des Senftenberger Braunkohlen-Flötzes," *Jahrb. d. k. preuss. geol. Landesanst. f. 1895*, p. 97 ff. Citations from separate, pp. 19–24.

as are observed in recent forests. These belong mostly to *Taxodium distichum,* the bald cypress of American swamps. Many of the stems are hollow and, especially those near the bottom of the mass, contain Schwelkohle. The presence of an ancient Torfmoor, resting on the clay cover of the brown coal, indicates that peat-making conditions recurred here until diluvial accumulations began. The sand overlying this old bog contains erect stems belonging to either *Pinus sylvestris* or *Picea excelsis* and stumps have been found in the peat itself. One great uncompressed fragment of a trunk was found by Potonié, but usually the prostrate stems are flattened. The presence of Schwelkohle in the hollow stumps led the author to suggest that it was formed by the flow of resins, which, he thinks, must have been great in the injured trees. Schwelkohle is, for him, essentially a fossil resin; it burns with brilliant flame when pure.

The forest of the roof is well shown in a photograph reproduced on a postal card, for which the writer is indebted to W. Gothan of Berlin. It shows ten or more erect stumps, 4 and more feet high, distinctly rooted in the coal and associated with some prostrate stems. These were overwhelmed by the detritus which brought peat-growth to an end. Kukuk[182a] has reproduced a noteworthy photograph of the Victoria stripping in Niederlausitz. The brown coal has been removed and the floor is exposed with the very numerous great rooted stumps of *Taxodium distichum.*

Russwurm[183] has given a section of the brown coal bed at Orebkau, about 50 miles south-southwest from Frankfurt a.O. and somewhat more than 10 miles northeast from Senftenberg. The bed is 9 meters thick, is divided by a thin parting and underlies 10 meters of mostly black clay, containing comminuted fragments of plants. The upper bench, free from wood, is lump coal (Knorpelkohle) and bears shipping, so that briquetting is unnecessary; but the lower bench is fine coal (Formkohle) and tender, but it is rich in wood, the quantity increasing downward until at the bottom the stems predominate. Russwurm found no erect stems. A second bed, at times 3 meters thick, is here at half a meter to 4 meters below the main

[182a] P. Kukuk, "Unsere Kohlen," Leipzig, 1913, p. 25.

[183] P. Russwurm, "Braunkohlen Formation, etc., bei Orebkau," *Zeitsch. f. pr. Geol.,* Jahrg. 17, 1909, pp. 87 ff.

bed; at one excavation, the beds are so near together that they are mined as one, but elsewhere they must be mined separately.

According to Katzer, the Bohemian brown coals belong to the Miocene. Grand'Eury[184] says that at Steinkirche near Budweis in southern Bohemia, the mass of lignite, at the bottom of a superficial basin, filled with sand, lignitic clay, wood, herbaceous plants and roots, is a forest peat covered with mud. Katzer[185] reports that in the Budweis area he saw a coal bed, consisting of an upper bench, 3 decimeters thick, with stems almost completely coaled, and a lower bench consisting mostly of Moor- and Erdkohle. At another place, a bed, 2 meters thick, holds here and there, a great abundance of stems and is so pyritous that it is utilized in the manufacture of vitriol. The same author[186] has described the Grottauer beds on the Neisse River, immediately south from the border of Saxony, which are in the middle or lower Miocene. In one shaft, 45 meters deep, 47 layers of alternating coal and shale were crossed. The important bed, reached at 4 meters from the surface, has four benches of coal, in all 10.35 meters, separated by three thin partings of clay and shale. Another shaft shows similar alternations but the succession differs somewhat, the second and third partings being irregular, sometimes absent. The principal bed has an extreme thickness locally of 16 meters in the western part of the trough, where dips rarely exceed 5 degrees and the beds show little evidence of disturbance, aside from crevices in the coal. The eastern wing of the trough is much disturbed, faults and folds occur frequently while the crevices in the coal, often still open and half a meter wide, extend downward 5 or 6 meters. Sulphates, chiefly alum, are shown on the walls of these crevices.

The Grottauer brown coal consists very largely of "fossilized wood." Freshly removed from the mine, it has a wood-earthy appearance; but when dried the blocks not only preserve the wood structure but show also the forms of stems, roots and branches, all

[184] C. Grand'Eury, "Sur la formation des couches de Stipite," etc., *Comptes Rendus*, T. 130, 1900, p. 1688.

[185] F. Katzer, "Geologie von Böhmen," Prag, 2te Aufl., 1892, p. 1425.

[186] F. Katzer, *Oesterr. Zeitsch. f. Berg. und Hütt.*, Bd. XLV., 1897. Separate, pp. 5–18.

pressed flat. The color is brown or reddish brown, but usually the bark is black. Stems and coals are not in separate layers but are intermingled. At times the coal is very impure and spaces between the stems are filled with loamy mud. Occasionally one finds nests of soft, deep black, sometimes granular coal, resembling linden charcoal. The fresh material can be worked with a knife, saw or plane; after complete drying, it can be pulverized only with difficulty. The wood-like coal, dried at 110° C., has carbon, 53.22, hydrogen, 5.56, oxygen and nitrogen, 37.95, ash, 3.27. This is better than the average as generally the ash is higher.

The "gas coal" of Falkenau occurs, according to Katzer, as the top bench of the middle coal bed at that place, and is somewhat more than 30 inches thick. The lower benches of the bed are thin, irregular and of poor quality. Von Gümbel's[187] study of this Falkenau material showed that it consists chiefly of much disintegrated vegetable matter. Treated with Bleichflussigkeit, it exhibits the needles of intermingled Faserkohle. With these are abundant pollen exines and very many minute bodies resembling those seen in diluvial brown coals. The deep brown spores of lichens or algæ are clearly recognizable. The voluminous mostly white ash, 7.75 per cent., consists of clay flakes and quartz grains with some fragments retaining plant texture. This composition, as ascertained by v. Gümbel, is very much like that of a Lebertorf.

The Lower Miocene deposits of Brennberg near Oedenburg in Hungary were studied by Nendtvich,[188] who described the coal as a lens. It has suffered much from disturbance, the dips varying from 40 to 50 degrees and crevices in the coal are filled with Russkohle (soot-coal) and slate. The thickness in the deeper part of the basin is from 10 to 20 fathoms, but the bed decreases toward the borders. The woody structure is distinct in some portions of the coal, which are finely fibrous and in part like ebony. The faux-toit is well-marked, consisting of alternating layers of coal and clay, and shows leaf impressions. According to Grand'Eury, the underclay contains no roots.

[187] C. W. v. Gümbel, "Beiträge," etc., p. 145.

[188] C. M. Nendtvich, "Ungarns Steinkohlen," etc., *Haidinger's Berichte*, Bd. III., 1848, p. 38.

Hantken[189] summarized the available information respecting the Miocene coals of Hungary. He found that the conditions in the middle Miocene resemble those in the Pliocene, in that the coal deposits occupy very small areas and vary greatly in thickness as well as in quality. A bed near Edeleny, 3.24 meters thick, has four benches; the clay partings are in all less than three fourths of a meter; one is pyritous, another contains *Helix* and plant remains and the third is carbonaceous. The underclay is carbonaceous and contains *Helix* as well as plant impressions. The deposits near Brennberg and Saljo-Tarjan are more important. The coal bearing group, at the bottom of the Miocene, is 27 to 40 meters thick and holds four coal beds at Brennberg, from 2 to 7.5 meters extreme thickness. The overlying sandstones are about 130 meters thick. At Saljo-Tarjan, the main bed is 2 meters thick, underlies sandstone and conglomerate and rests on marly clay. But Grand'Eury found that the floor varies. At an opening in Saljo-Tarjan, the coal rests on rhyolite-tuff, but at Mitra-Novak one coal bed rests on sandstone while another rests on clay.

Katzer[190] has described in considerable detail the brown coal deposit near Banjaluka in Bosnia, which, according to the fauna, appears to be Miocene, though its flora indicates Oligocene age. Tertiary beds occupy a basin of about 80 square kilometers and are surrounded by rocks belonging to different periods. The succession of psammites, marls, limestones and tender conglomerates is apparently freshwater throughout. The one important coal bed, mined near Banjaluka, is in three benches; the partings are very thin in the northwest part of the mine, where the bed is single; but they thicken rapidly, the upper and middle benches disappear in succession and only the lowest or Laũser bed remains. Where the bed is triple as in the Laũser district, the succession is: Hard limestones and soft marls, freshwater, 100 meters; marls, more or less carbonaceous, containing *Melanopsis;* upper bench of coal, with extreme thickness of 4 meters; gray to brown marls, calcareous, containing on top layers of compressed *Unio;* middle bench of coal, 2 meters; yellow to gray soft

[189] M. Hantken, "Die Kohlenflötze und Kohlenbergbau," etc., pp. 313–325.

[190] F. Katzer, "Die Braunkohlen Ablagerung von Banjaluka in Bosnien," *Berg. u. Hütt. Jahrb.*, Bd. LXI., 1913, pp. 153–227.

marls, with many films of bright coal and layers filled with compressed fossils, mostly *Planorbis* and *Melania;* Laũser coal or bottom bench, 2 to 2.5 meters; gray, brown to blackish sandy marls with thin-bedded calcareous marls holding coal smuts and carbonaceous shale.

In reading this section, one might easily suppose that it refers to some peat locality in northern Ohio. The coal differs somewhat in the several benches but the general character is the same throughout. The woody portions pass gradually into Pechkohle, which is the prevailing type and is not always laminated.

The Oligocene Coals.—In the Zsil Valley of Hungary, according to Hantken,[191] the great adit, which crosses 567 meters of Oligocene rock, dipping at 30 degrees, cuts 14 beds of coal, one of which is 41.12 meters thick. The marly beds in contact with the coal are very dark and contain carbonate of iron. At Szt. Ivan in the Gran district, a bed, 12.4 meters thick, has four benches of coal, the partings being freshwater limestone and in all 3.7 meters thick. It underlies a conglomerate of dolomitic fragments and rests on a carbonaceous shale passing downward into freshwater limestone. Partings in coal beds of this Gran area show notable variations in thickness, one of them increasing in a short distance from 1.9 to 17.45 meters. Freshwater conditions seem to have prevailed almost throughout, but in the Nagy-Kovacsier basin, the lowest coal bed underlies shale containing *Natica* and *Cerithium,* though freshwater limestones are the predominating rocks above. The coal shows marked variation in composition. Nendtvich[192] said in 1848 that the coal of the Gran region is black, with dull luster, mostly shaly but sometimes with conchoidal fracture. It is non-caking and yields only a slightly luminous gas. The woody character must be marked, for Nendtvich speaks of the material as tough and hard to pulverize. The chief drawbacks are the readiness with which it falls to pieces on exposure and the tendency to spontaneous combustion.

The Oligocene coals of Germany are found in many small areas. Plettner[193] described in detail the greater number of the compara-

[191] M. Hantken, "Die Kohlenflötze," etc., pp. 247, 259, 260–263, 280, 286, 289.

[192] C. M. Nendtvich, "Ungarns Steinkohlen," etc., pp. 25–31.

[193] Plettner, "Die Braunkohlen Formation in der Mark Brandenburg," *Zeitsch. d. d. geol. Gesell.,* Bd. IV., 1852, pp. 249–483.

tively small basins within Brandenburg, where the coals are of great importance. At Wittenberg, on the Elbe, where the bed is 8 to 12 feet thick, the coal is blackish-brown and pulverulent; the inhabitants wet it and mould it into bricks. The upper part of the bed contains much fine quartz sand, but there is none in the lower portion. The dips vary from 9 to 20 degrees. A rather extensive basin is near Muskau, on the Neisse River about 70 miles south of east from Wittenberg, where the coal is hard, imperfectly laminated and shows numerous imprints of leaves on surfaces of the laminæ. It rests on a fine clay and underlies about 10 feet of sand, succeeded by 5 inches of leaf-bearing clay, above which is another coal bed of unknown thickness. The coal is dull with earthy fracture and shows no trace of organic structure, aside from the leaf imprints. A yellow resin, mealy or dust-like, is abundant. At Grüneberg, 50 miles northeast from Muskau, the coal is hard and laminated; it is dark brown but the included plant remains, heaped in great quantity on the surfaces of laminæ, are yellowish brown. The waxy yellow resin is plentiful and is often enclosed in the fossil wood, especially between the annual rings.

Fürstenwalde is near the river Spree at a few miles west from Frankfurt a. O. Plettner has preserved the records of numerous shafts and borings, which exhibit such variations that the coal beds must be lenses. The dips are from 20 to 70 degrees. The important bed is triple. The great bench at the bottom, 10 to 11 feet thick, is the best and usually contains little Formkohle; but, at times, that type of coal forms most of the upper benches. There is a notable difference in quality, coal from the middle bench being the worst. Plettner in this district distinguished three types of coal, which he recognized elsewhere: (1) Knorpelkohle, the hardest and most appreciated, brownish to coal-black, with at times a bluish luster; it breaks into Knorpel or sharp-angled parallelopipedons, 2 to 9 inches in diameter; the fracture is earthy, luster none and plant remains are not common; (2) Erdig- or Formkohle, light brown, of loose texture, earthy, friable. (3) Bitumenöse Holz, which is present in all benches of a bed, embedded in the coal; sometimes it is fragmentary but at others whole stems are found; these are usually prostrate, erect stems being

rare. There is little difference in the wood and the fragments appear in all cases to belong to the genus *Pinus*. Ordinarily they are compressed and the annual rings are ellipsoidal. A yellowish-white resin, without succinic acid, is present in all types of the coal.

Buchow, west from Fürstenwalde, is at a few miles east from Berlin. There the coal is laminated with, as Plettner remarks, enough bitumenöse Holz to keep one from forgetting the vegetable origin of the coal, as he might do if he consider only the homogeneous substance in which the wood is embedded. At Freinwalde, 15 or 20 miles north-northeast from Berlin, the dip is only 10 degrees, whereas at Buchow it is 15 to 60. The coal at Freinwalde contains no wood and burns with a very disagreeable peat-like odor; this type, observed also at Buchow, is the Moorkohle of Plettner. Plant remains, recognizable by the unaided eye, are few, and such as were seen were pierced by threads of resin; but, in the neighboring area of Falkenburg, wood abounds.

This Moorkohle is shown near Frankfurt a. O. and at some other places. The dips in the basins of this eastern region vary from 10 to 60 and in one basin even to 90 degrees. At most localities the coal is laminated and contains resin as well as wood; the latter is often converted into Pechkohle and in that conversion it loses structure. Plettner calls attention t othe fact that the change into Pechkohle rarely affects the whole fragment. The converted portion is not altered by exposure to the air and does not separate into lamellæ.

The coals of Sachsen or Prussian Saxony have been studied by many observers. Laspeyres[194] examined an area near Trotha and Dolau, where the coal was mined by stripping. The lower bed is 2 to 6 meters thick and divided by an irregular parting of sandy clay. The upper bench is often so poor as to be worthless; the lower bench is better but consists chiefly of Formkohle with some Knorpelkohle. It contains much coarse or earthy retinite in nests, streaks or layers, as well as much pyrite, petrified wood and charcoal. At a little distance higher is the upper bed, with extreme thickness of 5 meters. This consists of Formkohle, small particles of brown-black coal, more or less closely packed together. Occasionally it is dust-

194 H. Laspeyres, "Geognostische Mittheilungen aus der Provinz Sachsen," *Zeitsch. d. d. geol. Gesell.*, Bd. XXXIV., 1872, pp. 298–302.

like and of cinnamon color, a Schwelkohle. Some Knorpelkohle is present along with bituminöse and petrified wood, the replacement in the latter being with pyrite or silica. The plant remains are chiefly wood, which predominates in some parts. This is wholly coniferous and, excepting a few Abietinae, belongs to cypress. Occasionally one finds great stems passing gradually into either earthy or compact coal, in which Laspeyres thinks he has proof that the varied conditions observed in coal must be ascribed to irregular working of the conversion process, though he is convinced that much of the earthy brown coal may be due to destruction of other parts of the plants, which, being tender, offered less resistance to the process and lost all structure.

Credner,[195] in discussing the same area, gives as the Oligocene succession: Lower, consisting of light-colored sands, clays with brown coals; Middle, dark gray to green gray sands and clays with marine forms; Upper, light-colored sands, gravels, clays with brown coals.

The Lower Oligocene, about 100 meters thick, is a mass of irregular variable strata. The coal beds are usually 4 to 5 meters thick but in places a maximum of 8 or 9 meters is reached. There seem to be practically two beds, but his general statement exhibits the irregularity of deposit, for he says, (1) That the beds are not continuous, but are interrupted locally, as they thin out; (2) Consequently only one bed occurs in places where two were expected; (3) It is questionable if these apparently local, lens-like individual beds are actually one and the same throughout, for the relations of the beds are extremely variable; (4) Locally, one finds more than two beds.

The coal is mostly earthy or soft brown coal, mingled with more or less of Knorpelkohle and bitumenöse Holz, the latter sometimes though not often replaced with pyrite and silica. The woody material is in small proportion and all the phenomena indicate swamp origin. In this connection he cites A. Penck's investigation of the Tanndorf brown coal, which showed that the lower shaly portion of the deposit is rich in well-preserved remains of floating plants,

[195] H. Credner, "Das Oligocän des Leipziger Kreises," *Zeitsch. d. d. geol. Gesell.*, Bd. XXX., 1878, pp. 615.

such as *Salvinia* and *Trapa;* the next layer is full of *Arundo* stems with leaves of *Salix,* evidently blown by the wind. Above this is the coal, composed of *Sequoia, Betula* and *Palmacites* stems. One sees here the gradual filling of a freshwater basin, through accumulation of *in situ* vegetation. The abundance of still erect tree stems, some rooted in the floor and others rooted in the coal itself and extending meters into the overlying sand, suggest that all the stems, prostrate as well as erect, are those of an *in situ* vegetation.

Naumann[196] remarks that stems, prostrate, piled irregularly and compressed, are often enclosed in earthy brown coal. At times, however, erect trees are found, cylindrical and retaining their roots, so that they are where they grew. One finds in these areas that locally all the prostrate stems lie in the same direction, showing that the same force had broken them off and laid them down. He adds a new example of erect trees. Some years prior to publication of his work, the brown coal had been exposed by stripping near Würzen in the province of Sachsen; on the surface of the coal, within a space of about half an acre, he saw between 40 and 50 trees, their roots interlocked within the coal bed.

A mineral, termed pyropissite, occurs at numerous places within Sachsen, sometimes pure but often mingled with ordinary brown coal to form the Schwelkohle, which has been of no little importance as a source of oils. Stohr's[197] description of conditions, prefacing his discussion of pyropissite, gives some details not recorded by the authors already cited. The strata generally are in no regular order and appear to dovetail; the brown coal alone appears to be well-defined. The formation is from 30 to 60 meters thick and underlies 3 to 30 meters of diluvial deposits. The roof of the coal is sand, clay or hard sandstone and there is a similar variation in the floor, though commonly that is plastic clay. The brown coal, where mined, averages about 6 meters, but the thickness varies from a few centimeters to 10, 16 and at one place 20 meters. Owing to irregularity in the floor, due to prior erosion, the coal occurs in shallow

[196] C. T. Naumann, "Lehrbuch der Geognosie," 2te Aufl., 1862, Bd. III., p. 204.

[197] E. Stohr, "Das Pyropissit Vorkommen in den Braunkohle bei Weissenfels und Zeitz," *Neues Jahrbuch,* Jahrg. 1867, pp. 407–409.

troughs but sometimes it crosses the separating ridge. Not unfrequently, there are "Sandsäcke," where the roof descends, at times, even to the floor. Usually these are filled with sand or gravel but sometimes with plastic clay. The coal is really in one bed, divided in some places by a sandy parting. The lower portion is Knorpelkohle, but is inferior as it contains much pyrite. The upper bench, though Formkohle, is a good fuel. Occasionally, a worthless, heavy, sand-like dust, termed Russkohle, composes whole layers in the bed. Pyrite, gypsum and retinite accompany the coal; at one place, amber, in lumps as large as one's fist, is found in the roof. Bituminous wood, pressed flat, as well as silicified wood is found in many mines.

Fiebelkorn[198] at a later date described the area examined by Stohr. Like him, he recognized only one bed, which where mined is from 4 to 21 meters thick and occupies a rather regular trough. Occasionally another bed, about one meter thick, is seen above it, the interval being filled with clay. The main portion of the trough is divided into numerous subordinate troughs separated by low ridges. Very often the coal is wanting on these ridges and the coal in the troughs is lens-like. The coal is usually earthy in type, a more or less friable mass of yellowish or reddish to dark brown or black material, coarse-grained, with rather shining streak and in general showing no organic texture. Toward the bottom, it not rarely becomes Knorpelkohle; but for the most part it is Formkohle and on drying falls into dust. The bed contains numerous coaled stems separated by spaces of one to five meters. The overlying beds are a succession of white and dark sands with some clay layers, all well exposed at several places where the cover is stripped. The floor is usually clay but sometimes sand. It is well shown near Teuchern and near Granschutz, where roots decending into it from the coal are distinct. He traced these in some cases to the depth of a half meter. They are those of reeds, grasses and rushes, marking the floor of a swamp.

Potonié regarded the Formkohle as, in most cases, of secondary-allochthonous origin. It was originally an autochthonous coal but had been removed and redeposited elsewhere. To this matter, refer-

[198] M. Fiebelkorn, "Die Braunkohlenablagerungen zwischen Weissenfels und Zeitz," *Zeitsch. f. pr. Geologie,* Jahrg. 1895, pp. 353–364, 396–415.

ence will be made in another connection. Raefler,[199] opposing the doctrine, examined closely most of the mines in the Sachsen area. Extended reference to this work will be made in discussion of the doctrine of Potonié. The plates illustrate well the lens-like form of the brown coals, showing isolation of the several portions of the beds and suggesting that the lenses were not wholly contemporaneous. The rudely crescent forms observed in cross-sections of the lenses with depressed upper surface make clear the effect of compression on the thick mass of vegetable matter midway in the little trough. Several of his profiles indicate "Sandsäcke" filled with "glazial Diluvium." The coal is very little disturbed in many places but in others the plications are very close. Some of these are evidently preglacial and the erosion was extreme; but it does not seem to have been contemporaneous in any case.

Pyropissite occurs in some portions of the Sachsen area. It is described by Zincken as amorphous, earthy, with earthy fracture; it is gray to yellowish to white, greasy to gummy feel and fuses to an asphaltic mass; it passes into Schwelkohle, a mixture of pyropissite and ordinary brown coal. Here only the geological relations may be considered; other matters belong under chemistry as of the brown coals.

Stohr,[200] in the memoir already cited, states that in southern Sachsen pyropissite is an integral part of the coal bed. The pure mineral yields 40 to 50 pounds of tar to the ton, from which paraffin and mineral oil are obtained; the ordinary material yields only 20 to 25 pounds. Until recently, the Schwelkohle was thought to be worthless and of rare occurrence; but, though absent from most of the area, it is present at many localities. It is not always a distinct bench, but at times forms laminæ in the upper part of the Feuer- or fuel coal. The distribution seems to be lens-like, for Stohr refers to nests of Schwelkohle. A variable layer of Russkohle intervenes between the Schwelkohle and the roof, ordinarily not more than 6 inches thick, but at one stripping he found this layer from 2 to 3 feet. He summarized his observations thus:

199 F. Raefler, "Die Entstehung der Braunkohlen lager zwischen Altenburg und Weissenfels," Inauguration Dissertation, Jena, 1911.

200 E. Stohr, *Neues Jahrbuch,* 1867, pp. 410–424.

Pyropissite occurs only where the cover is less than 16 meters; (2) it is sometimes the upper bench, but, where the bed is very thin, it is the only bench; it is not always limited to the upper bench but it may be distributed in the underlying Feuerkohle; it occurs as leaves in the main Feuerkohle, sometimes with distinct demarcation from the surrounding coal but at others passing gradually into it; (3) it is always accompanied by Russkohle, gypsum, and pyrite; retinite appears to be absent; (4) the character of the roof may be important; under gravel and sand it is better than under clayey conglomerate; but under a clay roof he has seen it both good and bad.

Von Gümbel[201] studied the pyropissite of Weissenfels. It is powdery, dust-like, brown-yellow and difficult to moisten. Under the microscope, it shows only indefinite grains, opaque lumps and scattered leaves, ill-preserved and belonging apparently to some moss. After removing the resinous substances by alcohol and ether and treating the residue with Schultze's reagent, he found little evidence of organic texture, aside from something like Faserkohle; there are some spiral threads, and spores and pollen are indicated by rounded patches. The ash, 14.2 per cent., consists of quartz grains, crystals and opaque black balls. No diatoms were seen. Pyropissite from Sauforst in southern Bavaria and of Miocene age, is in general much the same; but remains of grasses and of moss leaves are numerous, while pieces of wood are present, retaining structure though converted into a yellow friable material like the groundmass. After treatment with ether, the parts of leaves as well as the pollen grains become more distinct; pollen exines are very abundant.

Fiebelkorn, in the memoir already cited, gives sections showing the relations of Schwelkohle to ordinary coal. The bed at Grube 396 near Teuchern is only 6 to 7 meters thick, but at a little distance away it is 16, and, generally speaking, the whole bed is good. Some grains of coal are shown in the roof and the coal itself, especially in the upper part, shows alternating bright and dull laminæ. The section at this place is: Black earth, 0.60; loess, 7.50; Tertiary shale and sandstone, 6 to 8; impure coal, 0.30; Feuerkohle, 2.30; Schwelkohle, 0.50; Feuerkohle, 0.30 Schwelkohle, 4; Feuerkohle, 3; clay

[201] C. W. v. Gümbel, "Beiträge," etc., pp. 146–148.

and roots, 2.50. The measurements are in meters. Fiebelkorn makes no reference to the Russkohle, which Stohr found associated with the Schwelkohle. The distribution of the latter is quite different from that seen by Stohr, for here the two types of coal alternate. The Schwelkohle changes into pyropissite toward the border of the trough.

The Oligocene coal of the Cologne-Bonn region on both sides of the Lower Rhine has been mined during a long period. Davis[202] has given a brief description of the deposit near Horrem, which shows the general conditions. The brown coal contains about 60 per cent. of moisture and is soft, at most, slightly consolidated in the bed. Fresh from the mine, it resembles rather woody, half dry peat or muck from a swamp forest. The included wood, mostly lignite, appears, even when dry, to be no more changed or carbonized than the wood found in many peat beds. When dry, it is still soft enough to be whittled easily, the chips being scarcely more brittle than those from kiln-dried wood of similar types. The deposits range from 32 to 328 feet in thickness, the average being about 72 feet. The coal is covered with relatively thin gravel and clay; this overburden is removed by stripping, and the coal is mined in open cuts. The moist brown coal, as it lies in the bed, is nearly black, unconsolidated and contains a large percentage of fine material, which is friable even when wet.

The brown coals near Bonn were studied long ago by Horner,[203] who saw four types at the mines: (1) A dark brown or black earthy substance, friable to pulverulent, rarely showing lamination and found usually as the upper portion of the beds; (2) a cemented mass, in which leaves and fragments of wood are mingled with the earthy coal; (3) wood in different stages of bitumenization, with all shades of color from light brown to black, the last approaching jet; (4) Papierkohle, highly bituminous, burning with bright flame, separating into laminæ as thin as writing paper and leaving a white ash; it is a mixture of earth and comminuted vegetable matter. It should be

[202] C. A. Davis, "Production and Uses of Brown Coal in the Vicinity of Cologne, Germany," U. S. Bureau of Mines, Techn. Paper 55, 1913, pp. 5, 6.

[203] L. Horner, "On the Geology of the Environs of Bonn," *Trans. Geol. Soc.*, II., Vol. II., 1836, pp. 449, 450, 459.

noted here that "bitumenization" as used by Horner and others of the earlier writers is practically synonymous with "coalification" of some French writers and refers merely to the extent of conversion.

The several kinds of coal are found at times in a single bed. The wood is ordinarily in fragments of inconsiderable size, but sometimes large stems are found. These, when prostrate, the usual position, are flattened; but trees have been met with, erect, with roots attached and the stems passing through some benches of the coal. Horner thinks that these may have been floated in, being held in position by the weight of the roots. One of these trees was 7 and another 11 feet in diameter; the depth of water in which such trees could be floated must have been considerable. The writer has seen great floods on great rivers and he has seen many floating trees with roots attached, but he has never seen one floating in vertical position, except where it seemed wholly probable that the roots were loaded with earth or stones. If these trees near Bonn had been floated in erect position, the inorganic materials ought to appear with them. Horner states that the wood is often well enough preserved to be utilized in timbering the mines. Pyrite is common and "amber" occurs in irregular balls. The wood, at times, is replaced in part or altogether with carbonate of iron.

The section of a shaft at Utweiler is as follows: Soil, 2 feet 6 inches; loess, 9 feet 5 inches; basalt, 31 feet 9 inches; indurated clay, prismatic, changed by the basalt, 1 foot; clay, coaly, neither slaty nor columnar, 6 inches; black pitch coal, in prisms, perpendicular to face of the basalt and with dolomite in the interstices, 1 foot 2 inches; small coal, 4 feet; brown coal or bituminous wood, unaltered and with structure preserved, contains in the lower portion kidneys of compact clay-ironstone, 8 feet 6 inches.

The influence of the basalt disappears within 7 feet. The constitution of the thick bottom coal recalls the condition so often seen in the lower part of peat deposits formed by encroachment upon forested areas.

Heusler[204] has given a full description of conditions in the Lower

[204] C. Heusler, "Beschreibung des Bergreviers Bruhl-Unkel und des Niederrheinischen Braunkohlenbeckens," Bonn, 1897, pp. 32–42, 45–52, 132, 161, 163.

Rhine region. The important localities are Deutz, at a short distance west from Cologne, Bruhl and Unkel, about 25 and 45 miles south from Cologne. Other areas are as far as Linz, a few miles beyond Unkel. Three types of coal are found in this region; Blätterkohle or Dysodil, Alum brown coal and the Earthy brown coal which is manufactured into briquets. The first and second, limited chiefly to the upper portions of the basin in the Siebengebirge, extend northward on the left bank of the Rhine to Friesdorf near Bonn, while on the right bank they are found as far as Spick in the Deutz-Runderoth district. Heusler asserts that the difference in these coals has no relation to age and is due merely to local conditions.

Blätterkohle occurs in isolated patches near Linz, Orsburg, Oedingen as well as on the Hardt, especially near Rott. The deposits are irregular and alternate with clay, sand and ordinary brown coal. Near Linz, three layers were seen, 1.1, 0.78 and 4 meters thick, each containing more or less of lignite-like coal and many remains of aquatic animals, 10 species having been recognized. Near Orsburg, three layers were seen, separated by clay and poor coal; batrachians of several genera are abundant in the coal. In an isolated basin, this section was obtained: Hard earthy brown coal with lignite, 0.94; bituminous clay, 0.63 to 1.10; laminated siliceous beds, with leaf impressions, 0.16 to 0.26; Blätterkohle and Polischiefer, 0.26 to 0.78; lignite, pyritous, with leaf impressions and remains of fish, 0.63 to 1.10; semi-opal, 0.16; Blätterkohle, laminated, pyritous, some lignite, nests of Polischiefer, fragments of plants, insects, fish remains, 0.31; gray, pyritous clay, 0.31.

The measurements are in meters. The association with diatomaceous earth is by means unusual. Near Oedenberg, the Blätterkohle is very thick, but is so mixed with infusorial earth as to be of little value. In the Rott area, at the Krautgarten mine, the finely laminated Blätterkohle, at the bottom, is separated by almost 2 meters of grayish-white clay from a meter-thick bed of ordinary brown coal above. In this mine, the coals contain remains of mammals, amphibia, fish, insects of six orders, with crustaceans, mollusks and polyps as well as abundant plant fragments of many types. Heusler's description

shows that here one has a good example of pond-filling. The same relations are seen on the left bank of the Rhine near Oedenberg and Liessen; at the latter, Blätterkohle attains its greatest thickness, varying from 3.8 to 16.5 meters. The total area of rich Blätterkohle barely exceeds one square mile.

Alum brown coal, like Blätterkohle, is confined to the more southerly portions of the region containing the Oligocene basins; it is found especially on the Hardt near Putzchen and Spick on the right, and near Godesberg and Friesdorf on the left side of the Rhine, where it is associated with layers of ordinary and lignite-like brown coal. The Hardt area is about 10 by 4 kilometers and includes the Rott deposit already referred to. The coal there is 3 to 4 meters thick, mostly earthy brown coal and so pyritous that the ashes are used in the alum industry. Midway, is a meter of lignitic brown coal, composed largely of prostrate stems. One of these, a conifer, was 1,600 years old, that being the number of annual rings. But erect stems are by no means rare; one mine near Bleibtreu yielded 35 such stems in a space of 10 acres, the diameter varying from 0.78 to 2.82 meters or about 9 feet. Pyrite replaces or penetrates much of the stems and roots. This lignite on drying becomes black and changes into a typical Pechkohle. The plants are mostly conifers and palms. The relations of the coals are shown in a section measured near Friesdorf, thus: Loam and river drift, 5.2; brown coal and alum clay, 0.94; clay and bituminous wood, 1.26 to 1.57; brown coal (lignite), 0.16; bituminous clay, 0.31; brown coal and lignite, 0.16; gray pyritous clay with lignite, 1.57; brown coal, 2.51; black alum clay, 1.57; Blätterkohle, 0.47; lignite, 0.47; earthy brown coal, 0.94; Blätterkohle, 0.63 to 0.94; earthy brown coal, 0.47; Blätterkohle, 0.63 to 0.94.

The association of Blätterkohle and pyrite seems, from Heusler's sections, to be very intimate at most localities. Nineteen species of plants have been recognized at Friesdorf, a large part of them belonging to genera well represented in swamp floras. Erect stumps are at Füssenich and Stockheim.

Alumkohle and Blätterkohle become rare northward and earthy brown coal, like the Formkohle of Sachsen, is the usual type. Lig-

nite or bituminous wood is present in this coal and the species are like those as on the Hardt and at Friesdorf; stems are especially well preserved in mine Friedrich Wilhelm Maximilian, near Turnich on the Erft, but many of the Hardt species are not represented. Deposits between the Rhine and the Erft are quite regular, with clay floor, containing more or less brown coal, and often have a clay roof, but very frequently the cover is a diluvial deposit of varying thickness, through which water passes into the porous brown coal and downward to the clay floor; this surface water injures the coal. There is no distinction here into earthy brown coal and Schwelkohle as in Sachsen; the only difference is in state of preservation—earthy and lignite-like brown coal. The former is from the soft parts of plants and is utilized in manufacture of briquets; the latter yields the lump coal. It is not known whether or not any Schwelkohle like that of Sachsen exists in this region. The Schmierkohle, found in the Hangenden near Bruhl, is said to yield a greater proportion of distillation products than does the underlying earthy coal; but it is much mixed with clay and has a great percentage of water; both water and ash decrease downward in the mass of the bed. The thickness in the area of earthy brown coal varies greatly and abruptly; in the Bruhl-Liplar region it is from 5 to 104 meters.

The Rhenish brown coal contains in many places what is known as oölite wood, the woody matter being largely or wholly replaced with spherules of carbonate of iron. In searching the survey coal collections at Berlin, Gothan[205] found a piece of the brown coal from the Donatus mine near Cologne, which contained similar spherules of carbonate of iron. Deposition had not been confined to the wood, but had reached into the actual peat. Specimens were obtained from Flügel, who had mapped the area, and they proved to be a part of the bed replaced with material like that of the plant-balls described by Stur. Gothan suggested the name of Torfdolomite. Microscopic examination by Hörich showed that the plant remains as a rule are not well preserved; they are so disintegrated that in many cases they cannot be identified. Roots are best preserved, probably because they

[205] W. Gothan und O. Hörich, "Ueber Analoga der Torfdolomite (Coal Balls) des Carbons in der rheinische Braunkohle," *Jahrb. k. preuss. Landesanst.*, Bd. XXXI., Teil II., 1910, pp. 38–44.

entered when the surrounding mass had already become peat. They show no sign of compression. Some fragments of stems show the great lacunæ characteristic of plants belonging to a moist habitat. The great variety in the plants suggests that the deposit is a typical Waldtorf, which accords with the belief that the brown coals were deposited as Waldmoors.

Von Gümbel[206] examined the Blätterkohle obtained near Bonn. After treatment with Schultze's reagent, it showed under the microscope only scattered plant cells, exines of pollen, algæ-like clumps and some very indefinite particles, which appear to correspond to bits of animal matter. The descriptions by Horner, v. Gümbel and Heusler show that Blätterkohle is of sapropelic origin and that it is wholly similar to Lebertorf.

De Serres[207] described Oligocene brown coals in southern France. At the important gypsum quarries of Lac, near Narbonne, he observed that between the beds of gypsum there are others, marly and containing remains of plants and fishes, the latter being freshwater forms. Dysodil, like that of Sicily, occurs in layers between thick beds of marl overlying the gypsum. It is typical, in paper-thin laminæ and burns quickly with an abominable odor. Between the laminæ are enclosed imprints of fishes and plants, the latter apparently dicotyledonous. The number of fishes is prodigious; there are not merely imprints, there is even the actual substance, at times, in the marl beds and between the dysodil laminæ. The lower part of the section is mostly a limestone mass with lignites (brown coal). The succession near Caunnette is: (1) Calcareous sandstone, belonging to the compact gray macignos, exploited at Carcassone, 40 to 50 meters; (2) freshwater limestone, fissile, whitish, without trace of organisms; (3) limestone, very compact, with many fluviatile shells, *Lymnæa* and *Planorbis* being most abundant, 10 to 20 meters; (4) argillaceous limestone, allied to the macignos, 2 to 4 meters; (5) very bituminous freshwater limestone, divided by thin layers of hard, black, lustrous lignite, 10 to 12 meters; (6) carbonaceous shale, blackish, "nerf" of the workmen, contains numerous

[206] C. W. v. Gümbel, "Beiträge," etc., pp. 146–148.

[207] M. de Serres, "Observations géologiques sur le Département de l'Aude," *Soc. des Sci. Lille,* 1835, pp. 439–471.

Lymnæa and *Planorbis;* (7) first lignite, friable and of inferior quality, often has *Lymnæa* and *Planorbis* in top portion, 0.50 to 1 meter; (8) blackish carbonaceous shale, with river shells and kidneys of freshwater limestone; (9) second lignite, better than the first, but more irregular, 0 to 0.50 meter; (10) blackish carbonaceous shale with freshwater limestone, holding *Unio, Lymnæa* and *Planorbis;* (11) freshwater limestone, with more or less of lignite, 10 to 15 meters; (12) third lignite, very irregular, rarely thick enough to be mined; (13) irregular freshwater limestone resting on the nummulitic limestone.

Unio and *Cyclas* occur, though somewhat rarely, in the Caunnette lignite. Near the village of Songragnes, de Serres found lignites of apparently the same age, associated with blackish, bituminous marls, which contain much pyrite and some jet. The lignite encloses many nodules of amber, at times as large as a hen's egg. Some are translucent, others opaque, but all yield succinic acid. The noteworthy feature is the mass of freshwater limestone, with minimum thickness of 250 feet and interrupted only by freshwater carbonaceous shale with lenses of brown coal.

The Eocene Coals.—Molengraaff[208] has shown that coal-forming conditions existed in central Borneo during the Eocene. The coal is thin at most localities but occasionally it is of workable thickness. One exposure on the Mandai River has a bed, one meter thick, enclosed in shale and rich in carbonized tree trunks, which are partly silicified. Clayey layers of an overlying sandstone contain many impressions of leaves. On the Tabaoeng River, he saw a bed in three benches, 4, 1.40 and 2 meters respectively, separated by thin partings of shale and clayey sandstone, in which are concretions with plant imprints. The lower benches are fissile and evidently of poor quality, but the top bench consists of black pitch-coal, which seems to be good. These localities are within one third of a degree north and south from the equator. The sandstones of this coal-bearing group, not more than 40 meters thick, have grains of coal at many places and the associated volcanic tuffs, of undetermined age,

[208] G. A. F. Molengraaff, "Geological Explorations in Central Borneo," 1902, pp. 59, 60, 93.

contain erect and prostrate stems, which, according to Molengraaff, are distinctly *in loco natalis*.

Hutton[209] described important deposits of brown coal in New Zealand, which belong to the Upper Eocene. At one locality he saw two beds, 6 and 2 feet, underlying and overlying shales with leaves; the dip is 25 degrees. In another valley, the upper bed is 10 feet thick and has dip of 10 degrees. The mining operations are extensive and the coal everywhere is rich in "ambrite." In a later publication, he refers to bituminous shale near Dunedin and to a similar shale near Orepuke. That near Dunedin varies in thickness from 6 feet to 18 inches within a distance of 20 chains—a pronounced lens. It yields 42 gallons of crude oil per ton. The Orepuke shale is equally rich.

The coal of Häring, in the Tyrol, and its peculiarities have attracted notice from numerous students. Reuss[210] stated that the coal rests on gray to brown shale-clay, which becomes increasingly coal-like as it approaches the coal; at the same time it becomes more calcareous and finally passes into a crumbling coal, mixed with marl. It is rich in shells, *Helix, Planorbis* and a small bivalve, usually so crushed as to be unidentifiable. Some layers seem to be composed wholly of these shells; no remains of plants were observed. The coal, at times 30 feet thick, varies from Pechkohle to shining black "Schieferkohle" and nowhere shows any woody structure. The benches are 3 to 6 inches thick and the partings often consist of bituminous limestone, with nests of more or less shell-bearing limestone. The dip is from 30 to 35 degrees. The roof is a thin-bedded fetid limestone with many indistinct bivalves and, more rarely, *Fusus* and *Rostellaria*. It contains also abundant fragmentary remains of plants, among which *Salix, Erica,* palms and other forms have been identified.

Von Gümbel[211] speaks of this coal as embedded in undoubted marine marl deposits, containing both brackish water and freshwater

[209] F. W. Hutton, Reps. New Zealand Geol. Survey for 1871–72, pp. 107, 108, 181; "Geology of Otago," p. 110.

[210] Reuss, "Geognostische Beobachtungen durch Tyrol," *Neues Jahrbuch,* 1840, pp. 162–164.

[211] C. W. v. Gümbel, "Beiträge," etc., pp. 149, 150.

as well as land shells, along with remains of plants. The peculiar features of the deposit led him to recognize a condition analogous to that of cedar swamps on the low border of a bay. Treated with Schultze's reagent, the coal shows under the microscope that the bright layers are composed of leaves, epidermis and plant-parts with parenchymatous structure. The dull layers are more intricate. Faserkohle is quite abundant.

Haidinger,[212] 20 years earlier, had described a characteristic fragment of mineral charcoal obtained at Haring. He thought it probably an inclusion in the peat from which the brown coal was formed. This Faserkohle passes so gradually into the enclosing glance coal that Haidinger was inclined to believe it a case of external conversion into coal. At the same time, the Faserkohle is interwoven with vein-like lines of bright coal, which in his opinion could have been introduced only in a gelatinous condition like that of dopplerite.

Heer[213] notes that, near the Dürnten Schieferkohle area, a deposit of lignite occurs in soft sandstone of the Molasse. It often contains tree trunks but other parts of plants have become indistinguishable. Yet one finds marsh plants in the marls overlying the lignite, while the underlying limestone contains *Unio* and *Planorbis*.

The Bovey Tracey deposits in Devonshire, England, were described in great detail by Pengelly.[214] They had been subject of discussion during many years and the associated clays had been utilized on an extensive scale. The excavation, at the time of Pengelly's examination, was more than 100 feet deep, 350 feet wide and almost 1,000 feet long. His section, greatly condensed, is: Clays, sandy clays, thin sands and 4 beds of lignite, 7 to 15 inches thick; this lignite is poor, loose, brittle, woody; the clays are dark to gray, with streaks and fragments of lignite, 37 feet 7 inches; lignite with partings, 14 feet of lignite in 5 benches with about 7 feet of clay in the partings; the uppermost bench is more or less wood-like and at the bottom is a mass of dicotyledonous leaves; two of the clay part-

[212] W. Haidinger, *Verhandl. k. k. Geol. Reichsant.*, Bd. XIV., 1864, p. 241.

[213] O. Heer, "The Primæval World of Switzerland," Eng. Trans., London, 1876, Vol. I., p. 32.

[214] W. Pengelly, "Lignite and Clays of Bovey Tracey, Devonshire," *Phil. Trans. Roy. Soc.*, Vol. 152, 1863, pp. 1019–1038.

ings have streaks or fragments of lignite; the thick bottom bench is No. 25 of Pengelly's section, 20 feet 11 inches; clays and sands, stems and leaves are abundant in the upper half and thin streaks of lignite were seen in the lower part, 44 feet 1 inch; lignite with partings, 17 feet of lignite in 9 benches and 3 feet 2 inches of clay in the partings; the lignite benches are 3 inches to 4 feet thick, 20 feet 9 inches.

Roots descend from the lowest bench of the upper lignite into the underclay and the coal of that bench consists very largely of fronds of great ferns associated with leaves of other plants. The lower bed shows noteworthy variation in its benches. The third, descending, is woody and somewhat charred; the fifth and sixth are very hard and compact, not so tough as some of the others. The bottom bench is divided by a thin parting of "charred lignite" into an upper portion, 9 inches thick, which breaks into "irregular glassy pieces," and a lower portion, 3 feet 3 inches, which is hard light brown, less heavy than the ordinary lignite, is brittle woody and looks like ordinary coal. Mineral charcoal is present in all the benches. Of the about 50 species of plants recognized by Heer, Sequoias are most abundant and they form the greater part of one bed. Conybeare[215] has remarked that, in the Bovey Tracey area, one can see "the most decided wood pass into a substance no wise differing from common coal in chemical characters."

The Lower Tertiary coals of the United States of America are of great economic importance. They are of all grades from woody lignite to bituminous, even coking coal, and anthracite; and all are utilized. The basins and the fragments of basins which have escaped erosion are mostly in areas bordering on the Rocky Mountain region; but besides these there is a very extensive area in Texas and petty deposits are found in a few other localities west from the Mississippi Valley.

The deposits carrying brown coal in Texas have been grouped by Dumble[216] into the Timber Belt, the Yegua and the Fayette, the last

[215] W. D. Conybeare, "Outlines of Geology of England and Wales," London, 1822, p. 345.

[216] E. T. Dumble, "Report on the Brown Coal and Lignite Deposits of Texas," Austin, 1892, pp. 125, 135, 151, 165.

being the newest. Coal beds from a few inches to 10 or more feet thick are numerous in the Timber Belt. The enclosing clays, in many cases, are extremely dark and contain much silicified wood as well as lenticular masses of iron carbonate. Silicified wood is abundant in the Yegua.

Penrose,[217] in a publication of somewhat earlier date, described the lignite as occurring in a broad area, which in some portions extends eastward to within 150 miles from the Gulf coast. He separated the rocks into two divisions of which the upper may be Miocene. The coal beds are often double, as shown by a section in Robertson county, where the benches, 12 and 2 feet thick, are separated by 2 feet of clay. This is the important bed of the lower group and its coal is lignite, black, friable and woody. The upper group, along the Colorado River, has beds one to 10 feet thick, some of which contain masses of wood, including tree trunks partly silicified, partly lignitized. The coals of this upper group are all in lenticular deposits. Texas brown coals hold not only trunks, branches and leaves of trees but also reeds and other forms characteristic of swamp vegetation. In some beds, the coal shows distinct vegetable structure, but generally the mass of the material has been so thoroughly converted that no trace of structure is visible to the unaided eye. Frequently the coal is amorphous and soft, while at others it is hard, black, brilliant, with either cubical or conchoidal fracture—but all possible gradations exist between these extremes. The rocks throughout are undisturbed and coal of both types appears often in a single section. At the San Tomas mines, 25 miles above Laredo on the Rio Grande, a coal bed was seen with this structure: lignite, 2 inches; clay, 4 inches; coal, 1 foot 3 inches; black clay, 2 inches; coal, 1 foot 3 inches. The underlying clay contains just below the coal streaks of lignite—a faux-mur. The coals are massive glossy black and with conchoidal fracture, without trace of vegetable texture; but the thin top bench is a true lignite with the plant texture well-preserved. Kennedy[218] in the same state found

[217] R. A. F. Penrose, Jr., "Preliminary Report on the Gulf Tertiary of Texas," First Ann. Rep. Geol. Survey of Texas, 1890, pp. 26, 43, 52, 53, 94, 95.

[218] W. H. Kennedy, "Harrison County"; J. H. Herndon, "Smith County"; Second Ann. Rep. Geol. Survey, pp. 155, 156, 267.

at one locality, two embedded trunks, 16 and 20 feet long, 18 and 20 inches thick. The shorter stem was silicified throughout but the other was so at only one end, lignitized at the other; the conditions merging imperceptibly. At one place he saw a silicified stump, of which the interior had decayed before, silicification began. Herndon observed that within Smith county the coal beds are lenticular; the coal is brown to black, earthy to hard and frequently contains resin. Phillips and Worrall in 1913 estimated the brown coal area of Texas at not less than 60,000 square miles. The coal in many mines is very tender and the loss in screening even the freshly mined coal is very serious.

D. White[219] studied two typical localities in the Texas field, whence a lignite, not very wood-like, is obtained. The deposit near Hoyt in Wood county appears to have been made in a bayou or lagoon of irregular form, one half to three quarters of a mile wide, and it thins toward the margins. The floor is buff sandy clay, traversed locally by large roots of land plants, clearly in place. The coal, with maximum thickness of 9 feet, is dark brownish black, fairly well bedded, mostly moderately xyloid but with many lenses of brownish, more massive coal, with conchoidal fracture, waxy to satiny look, and amorphous; zones of well-laminated coal were seen. These, darker than the main benches, show cuticles and small woody particles, like much Palæozoic coal. The lenses are more or less canneloid. Amber is present in the upper part of the bed, which is distinctly xyloid; mineral charcoal is not abundant, but there is an inch parting which consists of densely matted fragments of charcoal. There were large trees, one log, partly silicified and somewhat flattened, was more than 70 feet long. The roof varies; at times it is "dirty coal," at others it is a bony coal and occasionally it is a carbonaceous clay, several feet thick.

The deposit near Rockdale was laid down similarly in an estuary or bayou, 10 miles long and one half to one mile wide. Two beds are worked by many owners in this area. The floor of the upper bed is gritty clay overlying sand and well-filled with roots, traversing the old soil in all directions at angles to the bedding; some of these are more than 3 inches thick. The bottom bench of coal con-

[219] D. White, "Origin of Coal," Bureau of Mines, Bull. 38, 1913, pp. 12–19.

sists of one to 3 inches of "black jack," a stiff, black coaly material with fragments of wood and stems. The coal is clean and solid for 6 feet; above that it is streaked with thin washes of white sand and dirt and irregular lenses of sand which seem to be in ripples. Higher, the sand washes are thicker and at length predominate, with intervening black muds, carrying waterworn vegetable materials. Above this is compact laminated clay, 3 feet thick, with many stems and traces of what appear to be roots. The upper part of the dirty coal, where it begins to be laminated, is rather distinctly marked with roots, branching rather irregularly downward and some of them appear to have extended a long distance into the coal below. Many of these seem to have rotted and the cavities to have been filled with white sand and clay, disfiguring the coal. Amber or fossil resin is abundant in some layers and the coal has joints, 10 to 12 feet apart. The lower bed rests on drab clay, filled with roots in place, which is covered by a thin layer of old humus, followed by more than 6 feet of black, splintery coal with conchoidal fracture, becoming dirty and laminated on top. On this rests light-colored clay with carbonized roots, 10 to 30 inches thick, which is succeeded by 6 to 18 inches of coal. Tree fragments are fairly common in this lower bed. White's description shows that the faux-toit is characteristic at both Hoyt and Rockdale; and that the faux-mur is present throughout at Rockdale.

At Lester, in Ouachita county of Arkansas, the lenses of canneloid coal are such that White regards them as presenting the lignite stage of cannel. The locality is in the Camden coal field, which is a small, irregular and very shallow basin with extreme dimensions of 7 by 15 miles. The rocks are unconsolidated sands and clays with some ferruginous sandstone. There is one workable coal bed, varying from 2 feet 6 inches to 6 feet, owing to the uneven floor. This floor is usually clay and holds no roots, except in one place, where it is sand and shows many roots in place. In one portion of the field, a carbonaceous mud forms the bottom of the bed and contains lignitized stems and twigs with fragments of ferns and dicotyledons. The roof is a light gray plastic clay. The coal or canneloid lignite has the general structure and appearance of a somewhat impure

cannel, is so soft and tough that it can be cut with a knife. It is free from foreign matter except at the bottom; occasionally a thin carbonaceous mud, with slender stems as jet-like fragments covers the coal and a thin xyloid bench was seen midway in the bed. The coal has high volatile, high illuminating power, high heating efficiency and gives copious yield of oil when distilled—the best yields 38 gallons per ton.

Thiessen,[220] in discussing this Lester material, says that it consists of vegetable débris from a herbaceous flora, but contains bits of angiospermous and gymnospermous wood, showing that a wood-flora existed. Everything is so well disintegrated and decomposed that very little is recognizable except the most resistant parts of plants. Exines of spores and pollen grains, resins and an undetermined waxy or resinous substance are conspicuous. The interstices are filled with more finely macerated parts of those constituents. Spores of fungi are present but are not abundant. The spore exines are mostly those of ferns, there being few from lycopods, while the pollen is both angiospermous and gymnospermous. Spores and pollen grains make up about 30 per cent. of the mass and are associated with abundance of cuticles. The resinous bodies are of two kinds, one, the lighter in color, is the more refractive and is paraffin-like in consistency; the other is less abundant and less refractive.

Eocene coals of the Rocky Mountains and adjacent areas are especially important within the states of Utah, Wyoming, Montana and North Dakota, where mining operations have been extensive at many places. The citations which follow are mostly from the more recent publications, as those of earlier date were made when opportunities for observation were not so good and dependence had to be almost wholly on natural exposures.

In one area within Utah, Richardson[221] found the coal between beds of freshwater limestone, black bituminous, containing abundantly the crushed shells of *Sphærium* and *Physa*. One bed is 36 feet thick, with 4 partings, of which the thickest is but two inches and a half. The rocks are faulted and the dip is from 10 to 15

[220] R. Thiessen, "Microscopic Study of Coal," the same, pp. 232–238.

[221] G. B. Richardson, "Coal in Sanpete County, Utah," U. S. Geol. Survery, Bull. 285, 1906, pp. 281.

degrees. The coal, as far as proximate analysis shows, is a very fair bituminous coal. The deposit is irregular and, in one direction, thins away within two miles.

Eocene deposits cover a great part of eastern Wyoming. Taff[222] found that, in the Sheridan coal field, the upper member of the Fort Union, about 2,200 feet thick, consists of friable, loosely consolidated sandstones, coal beds and slightly indurated shales, all with gentle dip, seldom exceeding 4 degrees. The coal beds are in three groups; the lower or Tongue River contains ascending the Carney, Monarch, Dietz, No. 3, No. 2 and No. 1, Smith and Roland coal beds, all of which are of workable thickness, the thinnest being 5 and the thickest somewhat more than 30 feet thick. The Intermediate group contains some lens-like coal beds, which at some places are of sufficient thickness for mining. The Ulm group or highest has two beds 16 and 12 feet. Nearly all of the beds are at least double and some of the highest beds are broken by partings. The coal is apparently almost uniform throughout; the weather attacks all alike. The only important distinction is that coal from the Intermediate and the Ulm has somewhat more water and shows the texture or fiber of some plants, whereas that from the Tongue River, though high in water, shows no woody texture to the naked eye. The thicker beds for the most part are without lamination; silicified wood is not rare.

Wegemann[223] examined an area contiguous to that studied by Taff in northeastern Wyoming and continuous with the extensive fields of eastern Montana and western Dakota. The exposed rocks, about 1,000 feet thick, belong to the upper part of the Intermediate and lower part of the Ulm, as defined by Taff. Wegemann saw many local unconformities and great variations in the rocks. A notable feature is the coarse sandstone filling channels in beds of coal and shale, due clearly to subaërial erosion. The cross-bedded sandstone denoting shallow water, the fine shale, proof of quiet water, the numerous coal beds and the repeated evidence of sub-

[222] J. A. Taff, "The Sheridan Coal Field, Wyoming," U. S. Geol. Survey, Bull. 341, 1909, pp. 127–130, 133, 144–147.

[223] C. H. Wegemann, "Barber Coal Field, Wyoming," U. S. Geol. Survey, Bull. 531, I., 1913, pp. 11, 12, 19.

aërial erosion are regarded as marking the presence of a great river, meandering over broad flats.

The coal is dull black with vitreous streaks and is brittle; but the woody origin is still distinct and fragments of *Sequoia* are abundant, associated with leaves of dicotyledonous plants. Trunks and stumps, erect or prostrate and partially silicified, embedded in the coal or projecting from the sandstone, are by no means rare. Coal beds are usually less variable than the other members of the section. The Healy coal of the Ulm group has been traced in an area of about 600 square miles, but the name designates a horizon rather than a coal bed. Where it is a single bed, it varies within short distances from a few inches to 18 feet, but often it is represented by a series of beds in a vertical section of 50 feet. This horizon is exceptional in extent, other beds, as a rule, having very limited area. One, 15 feet thick, quickly thins to a few inches and disappears; often a bed thins away and another is seen in the section at a little above or below its place. These are merely overlapping lenticular deposits. Contemporaneous deposits of coal are frequently separated by barren spaces. That these conditions, described in detail by Wegemann, are characteristic throughout Wyoming is evident from the incidental references by other observers.

Eocene deposits cover much of eastern Montana, extending northward across the state from Wyoming into Canada and eastward into North Dakota. The isolated basins of eastern Montana have been studied by several geologists. Woodruff and Woolsey[224] examined fields on the western side of the area, where they observed conditions hardly differing from those seen in Wyoming. Woodruff states that the coal beds with maximum thickness of 5 to 10 feet were evidently formed in basins. Many of them have carbonaceous shale, at times containing streaks of lignite, as floor and roof; at one mine he obtained *Unio* in the roof. Woolsey remarks that the coal beds in his area are very irregular and are lenticular. Resin is especially abundant in the Bull Mountain field, where the beds are

[224] E. G. Woodruff, "The Red Lodge Coal Field, Montana"; L. H. Woolsey, "The Bull Mountain Coal Field," U. S. Geol. Survey, Bull. 341, 1909, pp. 94–97, 103, 104: 62–77.

broken by many partings and the coal, more or less laminated, is jointed.

A small area examined by Rogers[225] is farther northeast; there the more indurated rocks of the lower division show mud cracks, cross-bedding and rippled surfaces. The coal of that division is brittle and fairly compact, though in some cases the woody texture is distinct. The coal of the upper division is mostly lignitic; but this distinction is not absolute, for vitreous coal is found in some of the higher beds and woody lignite is by no means uncommon in the lower division. Throughout, the coal beds are irregular; in all parts of the section, beds thin out and others appear at 8 or 10 feet higher or lower, so that Rogers is compelled to recognize horizons rather than contemporaneous separate deposits.

Farther eastward, beyond the Yellowstone River, one reaches the great lignite area with its numerous independent basins, which were examined by Bowen, Herald, Vance, Stebinger and Beckly.[226] The southern or Baker field shows mostly lignitic coal, woody in structure, brown and tough; the beds are broken by partings of considerable thickness and the benches are seldom of workable thickness. In the Terry field, all the deposits are irregular; the coal beds vary abruptly in thickness and character, often changing from coal to shale within a few yards. Even the comparatively persistent bed at the base is so irregular that Herald is inclined to speak of it as a "lignitic zone." The lens-like form of the deposits is characteristic throughout. The Glendive area is somewhat farther north. The lowest coal bed is apparently continuous along an outcrop of 150 miles, but Hance found it extremely variable in thickness and quality. Its coal is inferior to that of the bed, 50 to 150 feet higher. In places, two sets of joints are distinct.

Stebinger, after study of the Sydney field, which extends to the Canadian border, was not willing to admit that the lens-form is a persistent feature, though he recognizes fully the abrupt and ex-

[225] G. S. Rogers, "The Little Sheep Mountain Coal Field," U. S. Geol. Survey, Bull. 531 F, 1913, pp. 9, 11, 19, 20, 23, 24.

[226] "Lignite in Montana," U. S. Geol. Survey, Bull. 471 D, 1912; C. F. Bowen, pp. 21, 38, 39; F. A. Herald, pp. 56, 60, 62, 78; J. H. Vance, pp. 89, 92, 97, 98; E. Stebinger, pp. 106, 107, 115; A. L. Beckley, 152.

tensive variation in coal beds. Two beds appear to be really persistent for long distances; he had traced for 120 miles one which he regards as the equivalent of a bed in North Dakota. The coal is lignitic throughout, though it often resembles sub-bituminous. After weathering, the grain of the wood disappears, the color changes to black and the material is no longer tough, but is brittle. The greater part was formed from trunks of trees and fragments of wood; even entire logs, usually prostrate, can be traced on the fresh face of a mine. Coal in the lower 500 feet of the formation is less woody in appearance than that from the upper 500 feet. The extreme variability of the coal beds led him to infer that conditions were very unstable in the old moors. Beckly found the lignite very tough and wood-like in the Culberston field.

In considering the remarks on Montana areas, one must bear in mind that in most of the region the studies have been confined to natural outcrops and that tracing of the beds has been made in considerable areas by means of clinker lines, the burned outcrops. Extensive mining operations are concentrated, the localities being very few. The intervals between coal beds are reported as varying greatly. Speaking in a general way, it would seem that the measurements are too few for determining whether or not such variations are merely irregularities. The comparatively few detailed measurements are not enough to show the relations of the several benches of any bed in a large area. There is enough, however, to raise doubt respecting the actual continuity of the beds for any considerable distance.

Leonard,[227] in his synoptical description of the Dakota region, calls especial attention to the great variability of the accompanying rocks. The coal seams are from one inch to 33 feet thick and usually they are not persistent in extended areas. A seam may be pinched out or perhaps it may be replaced by another at the same or a slightly different horizon. Two seams may overlap, so that while both are to be seen in one section, only one of them may be present at half a mile away. Some can be traced in the river bluffs for

[227] A. G. Leonard, "North Dakota-Montana Lignite Area," U. S. Geol. Survey, Bull. 285, 1906, pp. 316–330; A. G. Leonard and C. D. Smith, "The Sentinel Butte Lignite Field," Bull. 341, Pt. 2, 1907, pp. 15–35.

several miles, but sooner or later they disappear. In Dakota, the coal is largely wood-like, tough and showing the grain; flattened trunks of trees frequently differ little from wood except in color. Often, the same seam is composed of alternating layers of tough, brown lignite and of black, lustrous more brittle material. The character of the coal changes toward the west; in Dakota it is woody and brown, but just beyond the Montana line it is largely lustrous; the same feature was observed still farther west at Glendive.

Leonard and Smith saw 9 coal beds of workable thickness, the lowest of which, according to Beckly, is about 400 feet above the Glendive bed—at the bottom of the Eocene. As result of broader studies, they modify the general assertion of lens-form and assert that some of the important beds have been traced continuously for 24 miles, while they have been correlated with much certainty for greater distances. Dips are very gentle throughout the region examined. Pockets of lustrous, black, textureless and brittle coal are scattered through many seams and are less pure than the lignite.

The Eocene coals continue into Canada, where they become less important and are overshadowed by those of the Mesozoic.

D. White[228] examined several localities within the Dakota region and gathered material, which was studied microscopically by Thiessen. The observations are so important that they must be given in full abstract. The coal bed, mined at Wilton, North Dakota, is near the bottom of the Fort Union or early Eocene, a freshwater formation, which stretches, in almost horizontal condition, from central North Dakota westward to the foot of the Rocky Mountains. At Wilton, the floor of the bed is white plastic clay, 4 to 5 inches thick, resting on white sandy clay and occasionally showing large roots in the place of their growth. The thickness of the coal is said to average about 7 feet, with a maximum of 14. The lowest 18 inches is a good lignite, broken by very thin clay partings; a half inch parting of mineral charcoal appears at several feet higher. A thin bench was seen, consisting of laminated coal, which resembles the bituminous types of Palæozoic and Mesozoic. The top coal includes a bony bench, formed apparently from dead aquatic or far-decayed vegetation mingled with mineral sediments, and a brownish

[228] D. White, "Origin of Coal," pp. 7–11.

layer near the bottom appears to contain grasses, stem fragments and chips of wood. The basal coal is almost black as are also the lenses or local layers of amorphous coal. When freshly mined, the mass is distinctly woody, tough and somewhat elastic; some large pieces are brownish-yellow as if from a recent bog. Often the "brown wood of a single piece verges into black, and even into a typical glossy lignite, having a conchoidal fracture and approaching jet. It is notable that the probable saturation with decomposition products in solution, that has produced the jet-like wood, resembling black vulcanized rubber, has not penetrated to the center of some of the fragments, which are inwardly brown or even yellow." Parts of some fragments appear to be charred while other parts are brown and woody. Wood makes great part of almost all the hard pieces examined, and logs, lying in all directions, are frequently in masses. To the naked eye, resin appears to be present in small quantity; silicified stems rarely occur.

The noteworthy features of the bed at Wilton, as summarized by White, are (1) an underclay, seemingly penetrated by roots; (2) evidence of periods, when herbaceous vegetation held the ground in certain areas and produced thin benches; (3) evidence of periods of great accumulation of wood of arboreal size; (4) relative scarcity of thinly laminated earthy or amorphous lignite (peat), this being dependent on the more or less nearly complete decay of the plant tissues; (5) evidence of frequent near approach to asepticity in the water body, so that decay seems to have been arrested quickly; (6) evidence that the surface was exposed at times to air, leading to formation of mineral charcoal. He thinks that the high water-content is a legacy from an unreduced or immature brown peat and also that the accumulation of logs, decayed only in part, indicates rapid growth of the coal.

The coal at Glendive, Montana, is very near the bottom of the Fort Union; it has been followed in a northerly direction for more than 50 miles. The fuel is dull black lignite, containing a large proportion of wood, sometimes in great slabs, both dull and jetified. No roots were seen in the underclay; mineral charcoal is present in a layer as well as in scattered pieces and the coal contains very many

lumps of amber-like resin, some of them apparently still attached to the wood. At the bottom of the bed there is a thin layer of dirty lignite.

The coal at Lehigh, North Dakota, is in the upper portion of the Fort Union, and the bed mined there is but one of many, 20 seams having been counted in one short section. Most of these had been laid down in freshwater swamps; usually they rest on underclays and frequently they have clay partings. The thickness is reported as varying from 6 to 8 and even more feet, "the greatest developments being found in the hollows of the floor, the coal thinning on all sides to the 'rise,' though on the whole it is relatively regular in bedding and thickness." The bed is singularly clean. The lower bench is free from all partings, except the charcoal layers, which are apt to be sulphurous. It is a dark brown, earth-colored lignite in which the large amount of wood is noteworthy. The grain of the wood is conspicuous as are also compressed trunks of trees with their branches, which compose about 75 per cent. of the whole. Some logs are gnarly, one to two feet wide and several inches thick. Some fragments are fully jetified, others partly so and others still, not at all, aseptic conditions having prevented decay. There seems to be little resin. The roof and floor could not be studied, but roots were observed in underclays of some higher beds.

Thiessen[229] studied the coals of Montana and North Dakota, collected by D. White. They are all xyloid lignites, consisting of 75 to 85 per cent. of woody material. The interstices are filled with débris from a large variety of plants and parts of plants, a binding stuff or "Fundamental matter." This semi-decayed, macerated, disintegrated material, composed of wood, parts of angiospermous and gymnospermous leaves, herbaceous stems, bark, roots, exines of spores, pollen, resinous and waxy bodies, cuticles, is cemented by matter, which apparently was once plastic. Spores and pollen exines form a considerable portion of the mass. The trunks of trees are wholly of conifers, mostly Taxadineæ and Cupressineæ, with a few Abietineæ, there being no stems certainly recognizable as dicotyledonous.

He compares the conditions with those observed by him in peat

[229] R. Thiessen, "Microscopic Study of Coal," pp. 221–232.

deposits within Michigan and Wisconsin, where *Thuja occidentalis* (white cedar), *Larix laricina* (tamarack) and *Picea mariana* (black spruce) abound, the *Thuja* being predominant. The growth is so dense that only a thin mat of mosses, liverworts and lichens with an occasional herbaceous plant can grow on the ground beneath. The peat, on which the forest stands, consists of logs and branches, lying in all directions, much changed and more or less macerated. The interstices are filled with "débris, in which macerated parts of stems and branches, cone scales, leaves, thalli of mosses and liverworts, pollen grains, etc., are plainly recognizable.

Nothing of algal origin was found in these coals.

The important coals of Eocene age on the Pacific coast are those in the state of Washington, where one finds all types of coal from peat-like lignite to hard dry anthracite, passing into graphite. Much of the area was studied years ago by B. Willis and G. O. Smith; but since their examination, mining operations have been developed on a large scale at many places, so that it seems best to utilize in this synopsis only the latest results.[230]

The Cowlitz River, rising in southern Lewis county, flows across Cowlitz county to the Columbia. The coal in this area is lignite throughout except where changed by eruptive rocks. At one locality, Collier saw a bed, more than 20 feet thick, as exposed in two open cuts, and composed of material "apparently little better than peat." It contains fragments of wood, which, though brittle, are flexible and elastic. Similar coal was seen in Lewis county, six miles away toward the northwest. The wood is so well preserved that one can whittle it easily. This fuel has little ash and is given to spontaneous combustion. Throughout the area, the coal is so woody that mining is difficult.

Some anthracite has been found on the eastern side of Lewis county, but most of the coal in that area is semi-anthracite to semi-bituminous: the beds are thin and the ash is high. At about 30 miles

[230] E. E. Smith, "Coals of the State of Washington," U. S. Geol. Survey, Bull. 274, 1911, pp. 152, 158, 161, 167, 180, 190; G. W. Evans, "Coals of King County, Washington," Washington Geol. Surv., Bull. 3, 1912, pp. 28, 29, 31–33, 59, 65, 116, 152; A. J. Collier, "Coal Resources of Cowlitz River Valley," U. S. Geol. Survey, Bull. 531 L, 1913, pp. 9, 12.

farther west, in the Ladd area, where dips vary from 32 to 40 degrees, the coal varies from anthracite to bituminous, both coking and non-coking; but in the Mendota-Chehalis area, about 30 miles farther west, the coal is sub-bituminous. Some of the beds in this latter area are more than 9 feet thick; the coal is massive, banded and, in some mines, is on the border line between sub-bituminous and lignite. The dips are from 12 to 54 degrees, mostly above 30. At Mendota, where the coal is grayish-black and low grade sub-bituminous, irregular lenses of soft, cannel-like coal are present. When freshly mined, these are black, but they quickly become brown on exposure. They contain so much volatile matter that when ignited by a match they burn like cannel with a long smoky flame.

In the northern part of Pierce county, 30 to 50 miles north from the Ladd area of Lewis, mining operations are extensive. Two beds at Burnett have laminated, good bituminous coking coal, which has been utilized in manufacture of illuminating gas. The dip is 45 degrees. At Pittsburg, two beds with dip of 58 to 60 degrees are mined and yield bituminous but non-coking coal. At Wilkeson, three beds, with dips of 20 to 60 degrees in different parts of the same mines, give a bituminous coking coal, well laminated, with varying ash in the several benches. The jointing is close and there is not much lump coal. At Carbonado, 12 beds have been worked, all of them more or less broken by partings and with dip of from 20 to 60 degrees. The coal is dense and bituminous, comparing very favorably with good bituminous coal from the Coal Measures. The lowest three beds are described as coking. At Montezuma, the coal is coking, semi-bituminous and the dips are 65 to 70 degrees. Resin occurs in low-grade sub-bituminous and to some extent in the higher grades within Lewis, Thurston and King counties.

Evans made detailed study of the coals in King county. Those in the western part have much moisture and are sub-bituminous, but farther east the bituminous type is not uncommon. The newer coals are more nearly lignitic than those from the lower beds. Throughout the whole column of about 8,000 feet, one finds great variation in composition and, far too often, the ash is so abundant as to make the coal worthless commercially. Several beds are quite regular in

occurrence within considerable spaces, but they change so abruptly in thickness, structure and composition that correlation in the different areas is impossible; the associated rocks are equally variable. The floor is usually clay or shale, often carbonaceous, but occasionally it is sandstone. Some parts of the county lost much coal during formation of pre-glacial valleys, now filled with glacial drift; while several coal beds suffered much from contemporaneous erosion and were replaced in considerable areas with sandstone. Evans notes tree trunks extending from the coal into the roof. D. White,[231] when at Rentoul in 1908, saw "kettle bottoms," or erect stumps of trees, 6 to 18 inches in diameter, standing directly on the coal, with black shale and coal filling the casts of the decayed boles. The coal is distinctly xyloid and jetified wood is strongly in evidence. Evans found a silicified erect stump showing the annual rings. Thiessen[232] ascertained that the coal collected by D. White contains a great proportion of débris, the quantity being almost equal to that of the woody matter. The woody component is coniferous and resinous; the débris is very resinous, apparently almost one half of its mass consisting of such material. Exines of spores and pollen are rather abundant but cuticles are rare.

The province of British Columbia, Canada, adjoining the state of Washington at the north, has a number of isolated coal basins, mostly of small extent. The available knowledge respecting the region has been digested by Dowling,[233] from whose work this synopsis is taken. It seems probable that the deposits are of Oligocene age in many of the places where the coal is economically important. In the Tulameen district, according to C. Camsell, the coal-bearing rocks occupy a basin in the older rocks, with an area of about 5 square miles. The section measured is about 2,500 feet and the middle portion, 460 feet, carrying the coal beds, begins at 600 feet from the bottom. Four beds with, in all, 20 feet of coal have been discovered and prospected. The coal throughout is in alternate bright and dull bands, the latter predominating; but the dull bands

231 D. White, "Origin of Coal," p. 24.

232 R. Thiessen, "Microscopic Study of Coal," p. 243.

233 D. B. Dowling, "Coal Fields of British Columbia," Geol. Surv. of Canada, Mem. 69, 1915, pp. 263 ff., 289 ff., 298 ff., 309, 321.

include many small lenses of bright coal. The dip is from 20 to 70 degrees, usually about 40. The ash, as shown by the analyses, is rather high, the samples being prisms from the whole bed. Some of the coal gives a strong coherent coke. On Hat Creek, G. M. Dawson obtained this section: (1) Grayish and brownish shales and sandy clays, with thin layers of lignite, about 20 feet; (2) lignite with shales, shaly and lenticular layers of silicious limestone, ironstone and shale; the lignite is fairly good, forms about two thirds of the whole and contains much crumbling amber, 26 feet; (3) lignite with little impurity, compact below, softer above, 42 feet, with the bottom not reached.

The lignite of the great mass is without foreign materials aside from irregular masses of calcareous or silicious stumps. Analyses show that the quality is good, there being only 9 per cent. of ash and 8.60 of moisture.

There are several small areas along the upper portion of the Fraser River; the lignite is unimportant but G. M. Dawson has given some notes respecting the rocks. The material of the upper beds is pale greenish and grayish white, very fine-grained and often a fire-clay; at times it is rich in diatoms. The beds are mostly horizontal but occasionally a local disturbance gives a dip of 20 degrees. Impressions of roots and branches are common and two silicified stumps, evidently in place, were seen. The beds turn up around the stumps and thin out toward them. The lignite, at the bottom of the section, is not in well-defined beds but is interstratified throughout with clays and appears to have been deposited as driftwood by somewhat rapidly flowing water; it is not pure enough to be of any value. Small spots and drops of amber are abundant in some layers. Little is known respecting the extent or importance of the other areas. The field geologists of Canada are in full accord with the palæontologists in the belief that these widely separated deposits were laid down in lakes or in estuaries.

The Eocene coals of Alaska have been studied more or less in detail during the last 40 years. Dall's[234] examinations were made in 1875, and the essential portions of his descriptions have been

[234] W. H. Dall, "Report on Coal and Lignite of Alaska," Seventeenth Ann. Rep. U. S. Geol. Survey, Pt. I., 1896, pp. 771–908.

republished in his report upon a reëxamination of the region in 1895. His studies were confined to the southern coast and the adjacent islands. Coal was discovered long ago on Admiralty Island, which is east from Baronoff Island, on which Sitka is situated. The first opening was made on Mitchell Bay and the coal was tested on the U.S.S. Saginaw, but the resin was so abundant as to render it unfit for use. The beds are very thin but, owing to the urgent need for fuel, they were studied carefully. The especial features are the woody structure and the abundance of resin. Kachemak Bay, near the mouth of Cook's Inlet, on the Kenai Peninsula, is 1,200 miles west from Admiralty Island. Furnhjelm, long ago, saw there a bed of coal, 9 to 11 feet thick, underlying clays, pebble rock and sands, and resting on partly bituminous laminated clay shale. It was black, brilliant and contained grains of amber. From the associated rocks he obtained *Unio, Amnicola, Melania* and elytra of a beetle, along with 44 species of plants, both conifers and dicotyledons. The bed was no longer exposed when Dall visited the locality, but, at Coal Point, he saw a bed 7 feet thick. In 1895, this bed had been opened at the Bradley mine, where it showed leaf-bearing partings and the best coal was at the bottom. Two other beds were examined on this bay, 4 feet 7 inches and 6 feet thick. These are complex. The coal differs in the several beds; that at the Bradley mine is evidently a glance, not soiling the fingers and, on drying, breaking into cubical fragments, whereas that from the Eastland mine is fibrous, dull charcoal black.

At Amalik Harbor, 150 miles farther west, some thin coal beds were seen, as also at Chignak, nearly 300 miles beyond. Amber has been obtained on the shore of Portage Bay southward from Chignak and from several other places in that region, as well as from several of the Aleutian Islands. Many thin beds of lignite were seen on Unga Island. One of these is very complex; the upper portion has half a dozen benches of bright and dull coal, each 4 to 5 inches thick, with thicker partings of carbonaceous shale. The bench is fairly clean and 18 inches thick. Analyses of coal from this bed gave

On the basis of pure coal, the volatile is 49.55 and 81.26 in the two

coals. Both are described as lignite but the composition of the lower bench, dull coal, suggests that it is of Lebertorf origin. Coal from a bed on Kachemak Bay is of the same type, as it has 71.3 per cent. of volatile.

	Water.	Volatile.	Fixed Carbon.	Ash.
Upper part	11.26	40.51	41.24	6.99
Lower part	10.58	66.21	15.26	7.95

Eldridge,[235] during examination of a district in eastern Alaska, discovered 10 to 15 deposits of low-grade lignite, 6 inches to 6 feet thick. The material resembles a mass of compressed carbonized wood. Stumps, one to two feet in diameter, are common and stand erect. These, by their appearance and by their association with abundance of slivers and other carbonized material, suggest that the coal beds originated in swamp vegetation. Occasionally, the coal shows no woody structure and resembles the higher grades of lignite, which shade off into bituminous coal.

Collier, not long afterwards, examined beds along the upper Yukon River, where the coal is either lignite or lignitic, little disturbed and usually contains amber. He visited a locality in the province of Yukon, Canada, 20 miles from Dawson and 7 from the Klondike, where R. G. McConnell had seen a double bed with 5 to 6 feet of coal, hard, without woody fiber and of practically the same composition in both benches. At 20 miles below Dawson, he saw 3 beds mined, all with one or more partings and all showing abundance of resin. At Washington Creek, 80 miles below the international boundary, he found a bed measuring clean coal, with thin partings, 5 feet 6 inches; dirty coal, 2 feet 6 inches; sandstone, 2 feet; shale, 2 inches; coal, 2 feet. The dip is 45 degrees, but there is neither crushing nor faulting. The coal is black, glossy and has conchoidal fracture, but it often shows woody structure and it contains streaks as well as grains of resin. The coal beds, seen by Col-

[235] G. H. Eldridge, "Reconnaissance of the Sushitna and Adjacent Territory, Alaska," Twentieth Ann. Rep. U. S. Geol. Survey, 1900, Pt. VII., pp. 21–23.

lier[236] at numerous localities farther down the Yukon, show the same general features as those already referred to.

Martin and Katz[237] found in the Matanuska region beds of dark fissile shale with bands of ironstone. The coal beds, in some cases, are thick and commercially good, but in others they consist merely of thin alternating layers of coal and shale, so that, though the coal predominates, the thick mass is worthless. The upper half of the section, about 1,000 feet, is composed chiefly of dark shales with thin beds of sandstone and many thicker beds of carbonaceous shale, which are leaf-bearing and include petty lenses of coal. The authors saw several fossil logs and tree stumps in an exposure, where one of them is 20 feet long and vertical to the bedding. Petrified fragments of wood appear to be not rare.

Henshaw[238] has given a brief note respecting the great bed on Chicago Creek, in Seward Peninsula and almost directly under the Arctic circle. The dip is 18 to 36 degrees and the thickness is 88 feet. The coal is frozen as in Spitzbergen and the modest mining operations are prosecuted during the short summer. The tunnel had been cleaned out only a short time before Henshaw's visit and he was able to make examination of the whole bed. It is an almost continuous mass of coal, broken only by a few layers of bony coal and sandy shale. Atwood[239] notes that in the Cook Inlet area, the coal beds are many, varying from mere films to 20 feet. At a mine near Tyonek, the coal is a tough, woody lignite and contains large trunks of trees, which are only partly converted. The mode of their occurrence suggests to him that they may be logs drifted into a pond or swamp, or that they are a group of fallen forest trees.

Tertiary coals have been observed at many localities in Siberia, but available notes respecting them are few and the age of the coals seems to be somewhat uncertain. The summary description of

[236] A. J. Collier, "The Coal Resources of the Yukon, Alaska," U. S. Geol. Survey, Bull. 218, 1903, pp. 17, 19, 22–26, 30–39.

[237] G. C. Martin and F. J. Katz, "Lower Matanuska Valley," U. S. Geol. Survey, Bull. 500, 1912, pp. 44–48.

[238] F. F. Henshaw, "Mining in the Fairhaven Precinct," U. S. Geol. Survey, Bull. 379, 1909, pp. 362.

[239] W. W. Atwood, "Mineral Resources of Southwestern Alaska," the same, p. 117.

Siberian resources[240] states that south-southwest from the Irtych River a thin bed of lignite was seen, which retains the woody texture and contains grains of amber. Lignite-bearing Tertiaries are of notable extent in the Transbaikal region; they are later in origin than the present topography of the country; the rocks show leaf impressions and contain silicified stems of dicotyledonous trees. The lignite beds are 2 to 4 meters thick but are lens-like, thinning away at the borders.

Some Chemical Features of the Tertiary Coals.—The literature dealing with the chemistry of Tertiary coals is voluminous, but comparatively little of it is serviceable for the present study. Analyses, for the most part, are of coal from localities where the fuel values had been proved long before the analyses were made: comparatively few are from deposits which are not important economically. In the United States and Canada, the samples are prisms from the whole face of a bed, only such partings being removed as should be separated from the coal before shipment. Analyses of such samples afford no clue to the varying conditions during accumulation of a bed. It is well understood that a proximate analysis of coal containing a high percentage of water yields at best only tentative results, varying in any case with the temperature employed. Ultimate analyses are, from the geologist's standpoint, little better, since coals of wholly different types may have practically the same ultimate composition, as was shown by Carnot. Coals are apparently mixtures of various hydrocarbons, respecting which very little is known, as only a few of them are acted on by solvents. But one must make use of the material within reach and much can be learned by comparison of analyses made after the same method; the official laboratories in the United States afford abundant material.

In studying the mature deposits of peat, known as Schieferkohle, v. Gümbel discovered a dopplerite-like material, which had saturated the mass and had become insoluble. A similar substance is in brown coal. Glöckner[241] examined the black lustrous coal, with conchoidal

[240] Le Comité Géologique de Russie, "Aperçu des Explorations géologiques et minières le long du Transsibirien," St. Peterbourg, 1900, pp. 42, 68, 87, 123, 153.

[241] Fr. Glöckner, "Ueber Zittavit, ein epigenetische, dopplerit-ähnliches Braunkohlengestein," *Zeitsch. d. d. geol. Gesell.*, 1911, pp. 418, 419.

fracture, which he saw in the brown coal of Zittau in Saxony. Siegert and Hermance had thought it identical with Pechkohle or Glanzkohle, but Glöckner objects to both terms as not specific, bcause they have been employed loosely in description of both brown and stone coals. He regards dopplerite as almost equally bad, because there is no agreement respecting it, except as to the fact that it is formed in recent peat moors. He prefers a new name for this tertiary substance, which is distinguished from dopplerite by its brittleness and its hardness, 2.5. Analysis of this zittavite, dried at 105° C., yielded carbon, 61.89, hydrogen, 5.32, oxygen, 30.43, nitrogen, 0.21, ash, 1.95. Comparing these results with those obtained by Demel, Kaufmann and Schrötter for dopplerite, one finds that Glöckner's material is more advanced than that studied by those chemists. They obtained for air-dried, ash-free dopplerite

	Carbon.	Hydrogen.	Oxygen and Nitrogen.
Demel	56.42	5.80	37.20
Kaufmann	55.94	5.20	38.86
Schrötter	51.69	5.34	43.03

One can hardly regard zittavite as a good mineral for, like dopplerite, it varies in composition and there would seem to be little reason for giving it a new name, except to distinguish the geological position. Glöckner recognizes similarity in origin, for zittavite is due to humic solutions formed during change of woody material into lignite and earthy brown coal, which circulate through the mass. He cannot believe that it results from action of calcium carbonate, because limy matter is but 0.47 per cent. of the whole. The characteristics suggest very close relationship to the carbohumin of v. Gümbel. D. White has expressed frequently the conviction that the conversion of wood into jet-like lignite is due to saturation by soluble compounds generated during decomposition of vegetable matter.

With comparatively few exceptions, students of the Tertiary coals have noted the presence in greater or less quantity of resins in streaks, nests or isolated globules, especially in coals of lignitic and sub-bituminous types, even occasionally in those closely allied to

the bituminous grade. The scanty notices of Pliocene coals contain few references to resins, the only definite note being that by Hutton respecting New Zealand, in which he states that the coal often contains large lumps of retinite. Thiessen found much resin in the Miocene coal of Monte Diablo of California; Brown and Potonié note the considerable proportion of resins in the coals of Greenland and southern Prussia. The Oligocene coals of Germany and British Columbia are rich in resin and, at times, it is found in cavities within fossil wood. Eocene coals throughout, when they are lignite or subbituminous, are notably resinous, material of that type occasionally composes a great part of the mass. The term retinite is employed frequently as a group name, but the resins are many. Amber or Bernstein, the best known popularly, has been reported from numerous places, widely separated. Dall states that it has been obtained at many points in Alaska; Daubrée observed it in the Bas-Rhin province and Potonié says that it is abundant at Senftenberg. But this mineral occurs in commercial quantity chiefly on the Baltic coast of Prussia, where, according to Karsten,[242] it is procured by digging and by dredging. In the former process, the recent sands are removed and the underlying clay shales, known as "amber veins," are exposed, in which are nests of brown coal and amber, apparently much compressed. These overlie coarse greenish sand, under which the important deposit is reached. This, with the overlying sand, extends under the sea and is the source of the amber, which is thrown on shore by the waves or is obtained by dredging.

Potonié[243] states that Bernstein occurs over the whole of North Germany, Poland, Russian Baltic provinces and Finland as well as in many other regions; but it is most abundant in Sammland, near Königsberg. There it occurs at three horizons. The original deposit is now below the sea, whence it is washed up by the waves; but these Eocene beds were gashed by glaciers and now the mineral is found also in glacial drift. The Bernstein forest grew on Cretaceous débris. This fossil resin, originally fluid, is an exudation

[242] H. Karsten, "Ueber das Vorkommen des Bernsteins an der preussische Küste," *Karsten's Archives,* Vol. 2, 1830, pp. 289, 290.

[243] H. Potonié, "Der baltische Bernsteins," *Natur-Wochensch.,* Bd. VI., 1891, pp. 21–25.

from a conifer, which Conwentz has named *Pinus succinifera.* The resiniferous organs were mostly in the bark and twigs but were abundant even in the wood itself. The conditions in these old forests were very similar to those observed in conifer forests of Bohemia: there could have been hardly any sound trees in the old Bernstein forests; wind, weather, saprophytes and other plant parasites, insects and other animals caused injury and led to flow of the resin. Bernstein is complex, consisting of gedanite, soft, yellow, transparent and fusing at about 180° C.; glissite, brown, opaque; stantienite, black, tender, brittle; bechanite, brown, tender, brittle; succinite, transparent, lustrous, yellow, brittle, fusing at 250–300° C.

The resemblance of these resins to some of recent age is very great and the origin is similar. They are exudations from coniferous trees and are resistant to decomposing agents, so that the proportion becomes greater as the process of decomposition advances in the vegetable material. Amber is associated, at times, with fragments of the trees whence it was derived, but in many places, as is the case with the recent kauri and copal, the woody materials have disappeared, leaving the resin free in the sands.

Pyropissite is locally characteristic of Oligocene coals in much of the Sachsen area of southern Prussia, where it, as well as Schwelkohle, a mixture of pyropissite and fuel coal, is distilled for the paraffins; it occurs also in the Miocene and Eocene of other regions. Karsten,[244] in a brief communication to the German Geological Society, described it as a peculiar earthy brown coal, which forms the roof of a bed near Weissenfels as well as of one near Helbra, between Mansfeld and Eisleben. It passes gradually into the ordinary brown coal, has gravity of 0.9 and leaves 13.5 per cent. of ash. At from 100° to 125° C., it gives off a heavy white vapor and at red heat the product is an oily liquid. Stirred in an open vessel, the whole mass liquefies and becomes pitch-like; in burning it gives off a disagreeable odor. The composition, ash and water free, is carbon, 68.92, hydrogen, 10.30, oxygen, 20.78, while that of the associated brown coal is carbon, 64.32, hydrogen, 5.63 [oxygen and nitrogen, 30.05]. The last two constituents are not given by Karsten.

[244] Karsten, *Zeitsch. d. d. geol. Gesell.,* Bd. II., 1850, p. 71.

Schwelkohle was formerly cast aside as worthless, but it has been utilized in the paraffin industry during later years as the supply of pyropissite is practically exhausted. As shown by Raefler the coal is richest in pyropissite on the borders of several petty basins, the proportion decreasing toward the middle. In the larger basin near Zeitz in Sachsen, the proportion of pyropissite becomes negligible as one goes eastward, but it increases again farther east, beyond the central line of the basin. The origin of the material is obscure. Potonié, in describing the Senftenberg coal, says that many of the stumps, *Taxodium distichum,* are hollow and those at the bottom contain Schwelkohle in the cavity. But the Schwelkohle in hollow stumps is not confined to the bottom of the deposit though it is more abundant there. He thinks that this substance was produced by flow of resin, which must have been great in the wounded trees; but one has difficulty in conceiving how a stump, which had been dead long enough to become hollow, could still retain enough vitality to pour out a great quantity of resin for healing of its wounds. Whether or not it is a resin may be open to discussion. The microscopic study of the Weissenfels pyropissite by v. Gümbel led to no definite results but in the Sauforst material he found a great quantity of exines of pollen. The mode of its occurrence seems to suggest that it is not unrelated to the Lebertorfs in origin. Potonié regards it as resinous and its occurrence as layers or smuts in what he recognizes as autochthonous coal is explained by the suggestion, that these may mark dry places, where the exposed coal was removed by decomposition and the resin was left unmingled with foreign matter.

It appears wholly probable that pyropissite was an original constituent, not a product of chemical action during conversion of the vegetable material. Kraemer and Spilker thought it formed by green algæ while Witt believed that it was derived from spores. Graefe, considering the contrast between pyropissite and the undoubted resin, retinite, cannot regard a resin as the source of pyropissite, and concludes that wax-like secretions of plants were in chief part the original material. Treated with benzol, pyropissite yielded 69.5 per cent. of "bitumen," while good Schwelkohle yielded 27.3 per cent.—the calculation in each case being for the dry substance. Raefler

says that the poorer the coal is in benzol extract, the richer it is in resin. "Bitumen" from pyropissite contains no resin soluble in ether, but that from bitumen-poor coal may contain 25 per cent.

Bredlick[245] states that Schwelkohle, when dried, resembles an earthy brown coal soaked in a wax-like bitumen. It is not homogeneous but consists of layers of richly bituminous lignite. It fuses at 150° to 200° C., thereby differing from fuel coal, which is infusible. He cites Riebeck on composition of pyropissite, which, ash-free, is carbon, 73.48, hydrogen, 11.70, oxygen, 14.80, while the associated fuel coal, according to Bredlick's analysis, has carbon, 64.78, hydrogen, 5.65, oxygen and nitrogen, 29.56. The several substances, when subjected to destructive distillation, yield

	Tar.	Water.	Coke.	Gas and Loss.
Pyropissite	64.2	7.7	16.3	11.8
Distillation coal	33.0	23.0	35.0	9.0
Fuel coal	5.0	63.5	25.0	6.5

Gas begins to pass off from pyropissite at 120° C. to 150° C., and the maximum temperature reached in the process is 640° C. The tar is of butterlike consistence when cooled, has gravity of 0.85 to 0.91, consists chiefly of paraffins and olefins, there being only traces of benzol and its homologues. This tar is fractioned and yields a paraffin free oil and paraffin wax, with a residuum. The last, about one third of the whole, is placed in another retort and heated to beyond the "cracking point." The gas from Schwelkohle is inferior; according to Graefe, its composition is: Carbon dioxide, 10.9; heavy hydrocarbons, 1.1; oxygen, 6.3; carbon monoxide, 8.5; hydrogen, 22.6; carburetted hydrogen, 6.4; ethane, 2.0; nitrogen, 42.2. The candle-power is from 8 to 12.

The Blätterkohle or Dysodil, which is a Tertiary Lebertorf, has been found in Sicily, France, Bohemia and other countries, but the most important deposits are near the Rhine in the Siebengebirge. The composition of material from Westerburg, according to Casselmann,[246] is: Carbon, 62.80; hydrogen, 6.76; oxygen and nitrogen,

[245] W. Bredlick in "Fuels Used in Texas," Bull. Univ. Texas, 307, 1913, pp. 169–178.

[246] Cited by C. F. Zincken, p. 180.

19.43; ash, 11.00. This coal, which is utilized, like Schwelkohle, for production of oils and paraffin, yields, according to H. Vohl,[247] by distillation: Water, 24.214; tar, 20.014; coaly residue, 46.326; gas, 9.446. The Blätterkohle of Rott yields 15 to 20 per cent. of tar on the large scale. This tar, when fractioned, gives: Photogen, 16; solarol, 24; paraffin, 20; hard paraffin, 4, from 100 pounds of tar.

Cannel-like coal has been reported from Washington, Alaska and Arkansas. That from Lewis county of Washington is extremely high in volatile, but no analysis is available. Analyses of two coals from Alaska show 71.3 and 81.26 of volatile. The Lester coal of Arkansas has 68.06 per cent., in the pure coal, and the best quality is said to yield 38 gallons of oil per ton. Lenses of cannel-like coal occur at Hoyt in Texas, but no analysis has been made. "Oil shale" of high grade has been found in New Zealand.

Analyses of brown coal, both proximate and ultimate, seem to be abundant enough for all purposes. Those from European localities are almost all from mines which have been long in operation and which yield coal proved to be marketable. In much of the areas within the United States, the coal has been mined in a small way to supply the owner's needs or those of a very small population; samples have been taken from these as well as from mines of great capacity, so that the reports from Government laboratories tell much respecting the variations in character. In almost every instance, the samples are prisms from the whole face of the bed, so that there is little information as to varying conditions during accumulation of the beds.

Comparatively few analyses of Pliocene coals have been reported. Hutton has given four for the Otago, New Zealand, basins and Hantken has given six for those of Hungary; reduced to pure coal basis, these are

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
Volatile	51.6	71.1	56.3	53.3	20.1	22.2	23.7	25.0	27.4	46.0
Fixed carbon	48.3	28.8	43.6	46.6	79.9	77.7	76.2	74.9	72.6	53.9

Hutton's specimens were air-dried and contained from 11 to 16 per

247 Cited by Heusler, p. 133.

cent. of water. The ash is from 2.80 to 29.58. The samples were evidently selected specimens and Hutton seems to think that the selection was not always judicious. The water in Hantken's samples varies from 17.57 to 27.2 and the ash is low, barely 5 per cent., except in No. IX., where it is almost 20 per cent. of the dried material. No relation appears here between the quantity of ash and that of volatile matter.[248]

Von Ammon[249] published several ultimate analyses from mines in Bavaria;

	I.	II.	III.	IV.	V.
Carbon......	68.64	69.42	62.76	69.70	65.90
Hydrogen ...	6.56	6.38	4.91	5.70	5.32
Oxygen	24.79	24.20	32.29	24.90	28.68

No. I. is a briquette with 10 per cent. of water and 13.21 of ash; No. II. is a fresh specimen from the Oettingen locality and contains 63 per cent. of water; No. 3 is lignit, bituminous wood, from Schwarzenfeld and No. IV. from the same place is woody; these have 41 and 36 per cent. of water but the ash is only 2.28; No. V. is a strongly dried brown coal, which has 24 per cent. of water and 9 of ash.

The number of analyses is small but they represent the best coals in the petty areas whence the samples were taken. Compared with peats, the proximate analyses show notable decrease in volatile, so great indeed in the Hungarian coals as to suggest the possibility of some metamorphic action. The ultimate analyses from Bavaria show an advance beyond mature peat in the carbon but it is not constant, for No. III. is poorer in carbon and richer in oxygen than some peats.

Miocene Coals.—Arnold has published two analyses from the Monte Diablo field in California, one representing a 5-feet cut at the top and the other, the lower part of the bed; Pardee has given two of the coal in southwestern Montana. These, made by the Bureau of Mines, show:

[248] F. W. Hutton, "Geology of Otago," p. 97; M. Hantken, op. cit., p. 341.
[249] L. v. Ammon, op. cit., pp. 18, 27.

	Volatile.	Fixed Carbon.	Sulphur.	C.	H.	O.	N.	Water.
I..........	54.57	45.43	5.64					
II.........	53.78	46.22	4.80	79.87	6.66	12.05	1.42	7.13
III........	52.90	47.10	1.53	70.42	5.08	21.64	1.33	6.93
IV........	59.20	40.80	2.15	72.20	6.73	17.93	0.99	10.00

The dips in the Monte Diablo area reach 70 degrees; the water in the coal is always low, sometimes not more than 3 per cent.; the ash is from 4 to 18 per cent.; but everywhere the coal seems to be very far from the bituminous grade. In southeastern Montana, the ash varies from 15 to 25 per cent.

The air-dried samples of Greenland coal, analyzed by Moss, as already cited, resemble a good bituminous coal, but the coal is a typical brown coal in all physical features. Miocene coals from Trinidad were analyzed by Percy, who obtained

	C.	H.	O and N.	Water.	Ash.
I...........	72.98	4.75	22.95	16.80	3.90
II..........	72.20	5.40	22.40	17.65	2.40
III.........	80.11	5.51	14.35	20.50	2.10
IV..........	77.16	5.83	16.89	5.90	3.44

In every case, the specimen for analysis was taken from the outcrop; all are attacked energetically by caustic potash. Experiments in the Survey laboratory showed that No. IV cakes. Resins appear to be wanting.[250]

A. S. McCreath's analyses of coal from the Miocene of Advent Bay, Spitzbergen, gave for different parts of the bed

	Water.	Volatile.	Fixed Carbon.	Sulphur.	Ash.
Upper part ..	3.310	19.790	62.763	0.467	13.670
Lower part ..	4.696	28.560	57.171	0.413	9.160

N. Dubois determined the ultimate composition of slack coal from the lower part of the bed, thus: Water, 4.14; carbon, 67.88; hydrogen, 4.05; oxygen and nitrogen, 11.90; ash, 12.03, or about 83 per cent. of carbon and 14 of oxygen in the pure coal. The notable features

[250] G. P. Wall and J. G. Sawkins, "Trinidad," etc., pp. 123, 126.

are the low water throughout and the great difference in volatile of the two parts of the bed, more than 9 per cent. in the pure coal. This coal is very similar in appearance to many Carboniferous coals but it is attacked by caustic potash to an unusual degree.[251]

Von Ammon[252] reports analyses from the small Miocene area in Bavaria, which exhibit much variability in composition.

	C.	H.	O and N.
I	49.01	5.15	45.82
II	70.93	4.25	24.81
III	60.43	4.47	35.08

The ash varies from 3 to 28 per cent. and the sulphur from 0.40 to 8 per cent. The first and third are very similar to peat in composition; the second is a Pechkohle from Schwarzen Moor.

The Grottauer coal of Bohemia contains, according to Katzer, 50 per cent. of water when freshly mined; dried at 110° C., it has carbon, 53.22, hydrogen, 5.56, oxygen and nitrogen, 37.95, ash, 3.97. The sulphur, as pyrite and in organic combination, sometimes reaches 3.84 per cent.

The Hungarian coals show considerable variation in composition. Nendtvich[253] gives analyses from two beds thus:

	Water.	Volatile.	C.	H.	O and N.
Rudolphilager	18.68	49.11	70.849	4.715	24.445
	17.00	44.02	72.185	5.185	22.630
Josephilager	17.82	67.00	72.490	5.175	22.235
	17.10	54.00	71.360	5.095	23.545

These are from near Oedenburg; having been made according to the same method, they are comparable. They make clear that for comparisons one needs both ultimate and proximate analyses. The second from Rudolphi and the first from Josephi have almost the same ultimate composition, yet the latter yields about 23 per cent. more volatile than the former, showing that it has very different constituents. The analyses for each are from different portions of

251 In *Annals N. Y. Acad. Sci.*, Vol. XVI., 1905, pp. 86, 87.

252 L. v. Ammon, op. cit., pp. 62, 64.

253 C. M. Nendtvich, "Ungarns Steinkohlen," etc., pp. 40–44.

the bed. The ash varies from about 2 to 5 per cent. Hantken[254] gives three analyses, which are equally illustrative; one is of coal from Édéleny and the other two from near Brennberg.

	C.	H.	O.
I	53.85	4.21	41.94
II	71.92	4.95	23.53
III	71.90	5.14	22.89

These are all used as fuel; at Édéleny, the ash varies from 15 to 21 per cent. and the water from 21 to 61 per cent., so that the fuel is of decidedly poor quality; but at Brennberg, the water does not exceed 18 per cent. and the highest ash is 3.45. These Miocene deposits are confined to very small areas.

Oligocene Coals.—These are of great importance in Prussia and in Hungary. Hantken[255] has given proximate analyses of coals from the Zsil valley and from two parts of one mine near Gran:

	Water.	Fixed Carbon.	Ash.	Volatile.
I	4.83	58.50	6.55	36.67
II	14.09	59.53	3.55	22.53
III	12.727	38.035	8.217	40.921

Ultimate analyses from two localities in the Gran area, including the mine already referred to, have been given by Hantken and four others were published by Nendtvich:

	C.	H.	O and N.	Volatile in Pure Coal.
I. Szt. Ivan	64.92	4.94	30.10	
II. Gran	69.30	4.80	27.00	27.45
III. Gran	68.58	4.67	26.75	51.82
IV. Tokodt	67.495	4.70	27.80	31.30
V. Sarisap	67.85	4.83	27.22	38.77
VI. Csolnok	71.55	5.19	23.25	47.44
VII. Zsemli	71.89	4.79	23.31	40.45

The two coals from different parts of the mine at Gran have practically the same ultimate composition, yet in the pure coal there is a difference of 23 per cent. in the volatile. The contrasts are not

[254] M. Hantken, op. cit., pp. 315–325.

[255] M. Hantken, pp. 247, 259, 260, 262, 280, 286, 289; C. M. Nendtvich, p. 32.

so great in the coals analyzed by Nendtvich, but there is a difference of 7 per cent. in the volatile of two coals with essentially the same ultimate composition. The water in these Hungarian coals is from 4.83 to 17 per cent. and the ash from 4.23 to 11 per cent.

The coals of Brandenburg, in the region studied by Plettner, show notable variation, according to analyses reported by Zincken;

	C.	H.	O and N.
Perleberg, Erdkohle	66.32	5.20	28.48
Frankfurt a. O., Knorpel	65.60	5.36	29.04
Neudorf, Formkohle	60.00	6.56	33.44
Fürstenwalde, Formkohle	70.64	5.22	24.14
Knorpelkohle	68.37	5.47	26.16

A great part of the Sachsen coal is Formkohle, which according to analyses by Karsten and Bredlick, cited on an earlier page, contains from 62.74 to 64.32 of carbon and the oxygen varies little from 30 per cent. The analyses of the Brandenburg coals seem to indicate that the composition and the physical structure of the coal are not related, Formkohle being highest and lowest in carbon as well as in oxygen. These Oligocene coals differ not much from mature peat in their composition.[256]

Katzer analyzed two samples from an opening in the Lãuser bench of the bed near Banjąluka in Bosnia, which show no great variation;

	C.	H.	O and N.
I	74.51	5.08	20.41
II	71.83	4.96	23.11

The water is from 21.82 to 29.05 and the ash, 7.40 to 8.45; sulphur is high, from 6 to 7 per cent.

The Oligocene coals of British Columbia are, in many cases, bituminous; the region being more or less affected by eruptive rock. It is not certain that the analyses reported give any clear conception respecting the general character of the coal, as the samples analyzed were selected from the outcrops.

[256] C. Zincken, pp. 28, 29.

Eocene Coals.—The analyses of Southland coals in New Zealand, reported by Hutton, are all proximate; they show the volatile varying from 39 to 63.74 in the pure coal, while the water is from about 15 to 17 and the ash from 2.80 to 12.45 per cent. The samples appear to have been selected and not to be representative of the whole bed. No relation appears here between the proportion of ash and that of volatile. Zincken has given an analysis of the English Bovey Tracey coal, apparently by himself, and Dana[257] has published an analysis by Vaux. Ash and sulphur free, these are

	C.	H.	O and N.
I	69.95	5.93	24.11
II	69.52	5.90	24.56

The Eocene coals of Texas are mined extensively at many localities and Phillips and Worrell[258] have made numerous analyses, the samples having been collected in all cases in accordance with the official method. The composition of these coals varies greatly, even in a single bed within a limited area. The conditions are clear from comparisons of the samples taken from several mines near Rockdale in Milam county. All are reduced to pure coal basis except for water and ash, which are for the coal as received:

	Water.	Ash.	Volatile.	Fixed Carbon.	C.	H.	O and N.
1538....	32.79	10.70	61.8	38.1	69.71	5.54	24.74
1539....	34.72	11.76	60.8	39.1	73.63	5.48	20.87
1540....	32.27	12.05	74.3	25.5	67.36	4.99	21.64
1541....	33.63	18.27	86.2	13.7	72.84	5.07	22.08
1542....	31.52	9.45	71.7	28.2	67.38	5.50	27.11
1543....	29.07	26.47	54.2	45.7	77.11	5.46	17.41

The samples are all from the same bed and are in close proximity; it is clear that no relation exists between ash and volatile matter. It is equally clear that the conditions were not the same throughout the basin during accumulation of the peat. This appears from the

257 C. Zincken, p. 28; J. D. Dana, "Manual of Geology," 1895, p. 662.

258 W. B. Phillips and S. H. Worrell, "The Fuels Used in Texas," pp. 85–89, 91, 92, 98, 100.

variation in percentage of the ash; but it is more apparent when one considers the composition of the ash in the several samples:

	Silica.	Alumina.	Ferric Ox.	Calc. Ox.	Magnes. Ox.	Sulphuric Acid.
1538.....	21.64	16.20	11.10	25.23	4.36	18.01
1539.....	33.06	16.77	8.47	23.00	1.28	17.10
1540.....	27.44	28.87	24.85	7.00	0.00	10.45
1541.....	23.20	11.94	5.08	38.17	1.00	7.79
1542.....	42.20	23.02	2.02	15.93	2.12	12.81
1543.....	47.04	23.18	18.32	6.64	0.00	4.58

In these coals one has another illustration of indefiniteness of analyses as indications of the actual composition of coal. Nos. 1539 and 1541 have almost the same ultimate composition, yet there is a difference of more than 25 per cent. in the volatile.

Analyses of coals in the Wyoming-Montana-North Dakota region are numerous. Taff and Wegemann cut samples in the Sheridan and Barber fields. Ten beds were sampled in a vertical section of about 1,900 feet. The variations in composition are less than those found within a single bed in the Rockdale area of Texas. The volatile in the lowest bed is 46.30 and that in the highest is 47.67; but in one midway in the section it is 44.69, and in the one next above it is 53.20, while in the next to the highest it is only 43.97. The carbon varies from 74.37 in the lowest bed to 70.97 in the highest, but in a bed almost midway in the section it is 71.96. The oxygen is 20.42 in the lowest bed and 22.95 in the highest, but is lowest in an intervening bed. The coal throughout this region appears to be remarkably free from inorganic matter, as the ash varies from 4.10 to 9.95 per cent. of the dry coal and it is usually less than 7 per cent.[259]

Somewhat farther north, in the Red Lodge field of eastern Montana, samples were cut by Woodruff and were analyzed at the same laboratory. Eight analyses were made of six beds exposed in a section of approximately 475 feet. The volatile is from 37.35 in the lowest bed to 45.85 in the highest; but in another analysis, the lowest bed shows 43.35 and the fifth bed, ascending, has but 42.66. The carbon is 72.66 in the lowest and 74.41 in the fifth bed, while in the

[259] U. S. Bureau of Mines, Bull. 22, 1913, pp. 307–309.

same beds the oxygen is 20.77 and 16.94 in the two analyses of the bottom bed while it is but 17.85 in the fifth. The ash is from 6.02 to 13.31 per cent. of the freshly mined coal, which contains 8.60 to 11.69 of water. Much of the coal, according to these analyses, would be regarded as inferior. In this field, as in the Sheridan, there is no relation between ash and volatile and comparison of analyses shows that position in the section is not very important. Proximate analyses from the Miles City field in Montana tell the same story, for the volatile varies from 42.49 to 49.60 in sound coal from the lowest bed, while a single analysis of crop coal from a bed, 800 feet higher, shows 48.09. Water in the lowest bed is from 29.25 to 43.70, while that of the highest is 35.51.[260]

Analyses were made of 7 samples cut in the Snyder mine near Glendive on the eastern border of Montana.

	Water.	Ash.	Volatile.	Fixed Carbon.	C.	H.	O and N.
2423	39.94	5.61	45.40	54.60			
3812	34.55	7.20	60.67	39.33	72.79	4.74	20.58
3815	33.65	6.90	49.84	50.16	67.87	3.97	26.80
3816	34.89	8.07	76.23	23.77	73.04	4.43	20.20
3817	31.26	6.80	68.49	31.51	70.92	4.07	23.72
3819	33.06	8.33	51.70	48.30			
3820	33.06	6.26	65.62	34.38			

Ultimate analysis was made of only four samples. In all cases, sampled by the official method, the coal is sealed in waterproof cans at once, so that it reaches the laboratory in fresh condition.

The ash varies in this small mine from 8.62 to 12.44 per cent. of the dried material; no relation exists between it and the volatile; 3816 and 3819 have practically the same ash, 12.39 and 12.44, but there is almost 25 per cent. difference in the volatile. 3815 and 3816 have almost the same ultimate composition, but their volatile differs by almost 16 per cent.

The Leonard and Smith samples are from eastern North Dakota, and their bed *C* is taken to be about 300 feet above the Glendive bed; bed *G* is somewhat more than 250 feet above *C*.

[260] The same, Bull. 22, pp. 124–126.

	Water.	Ash.	Volatile.	Fixed Carbon.
2428 *C*	38.45	5.69	50.16	49.84
5779 *E*	34.50	7.51	51.05	48.95
5782 *E*	35.72	8.86	57.53	42.47
5782 *F*	35.40	5.64	64.86	35.14
5784 *F*	43.51	6.39	50.37	49.63
2427 *G*	29.78	6.56	50.74	49.26

No ultimate analyses of these samples were made, but the proximate analyses suffice to show the great variability in conditions under which the coals accumulated; there is notable difference in ash; in the two analyses of coal bed *F* one finds a difference of more than 14 per cent. of volatile.

The coals of the state of Washington have great economic importance and a great mass of analyses is available. In that state one finds all grades of coal from peat-like material to graphitic anthracite within the Eocene column; at many localities the coals yield coke of excellent quality. One may select only a few of the analyses as illustrating the variations. In King county the water is low, rarely exceeding 12, usually below 9 and in a great number of cases is below 6 per cent. in the freshly mined coal. The ash is high, not often below 12 and very frequently above 20 per cent. in the dry coal. The first five analyses, which follow, are from the several beds near Issaquah and are of subbituminous coal; the sixth is bituminous and the seventh is of coking coal from Bayne.

	Water.	Ash.	Volatile.	Fixed Carbon.	C.	H.	O and N.
8544 I	14.2	13.59	40.9	59.1	76.51	5.66	17.34
8445 II............	13.8	20.53	47.3	52.7	74.77	6.00	18.51
11736 III...........	15.9	11.4	48.4	51.6			
11737 IV...........	16.5	24.4	52.4	47.6			
8543 V............	15.1	13.36	39.9	60.1	75.52	5.41	17.55
9114..............	4.9	4.74	46.2	53.8	79.96	5.86	13.67
9485..............	4.2	11.62	38.3	61.7	81.52	5.65	12.30

At Ronald in Kittitas county, a coking coal is found with composition differing very slightly from that of the coal at Bayne. In Pierce county, coking coals are mined at many places with 3 to 5 per cent. of water in the fresh coal; the ash is rather high in some of them,

reaching even to 16 per cent. of the dried coal; not a few of these coals have 84 to 87 per cent. of carbon. But not all of the beds yield caking coal, even where its composition is closely similar to that of the others.

The coals of Lewis county show extremes of variation, for there one finds anthracite with 6.8 of volatile and 93.2 per cent. of fixed carbon in the pure coal, whereas at Mendota the coal is lignite with 20 per cent. of water and 73 per cent. of carbon. At Ladd the coals are bituminous and that from No. 2 is coking. It has 4.1 of water and 84.62 of carbon. It yields 34.2 per cent. of volatile from the pure coal. The other beds mined on this property have only 6 to 8 per cent. of water but the volatile is much higher, 43 to 48 per cent., and they are not caking. The ash throughout is high, 18 to 26 per cent. of the dry coal.[261]

Igneous rocks are reported as cutting the coal bearing rocks at a few localities in King and Pierce counties, but for the most part the variation in the coals is regional and apparently is not due to local causes.

The Alaskan coals show all types from lignite to anthracite. The anthracite coals are in the Bering River region where the carbon content at times reaches 90 per cent.; but in the same region are bituminous and semi-bituminous coals. The lignitic type, however, prevails in the greater part of the territory.

	C.	H.	O and N.	Volatile.
I	67.45	5.27	26.63	64.44
II	69.08	5.28	25.16	50.86
III	68.77	5.02	25.93	50.53
IV	68.47	5.53	25.37	55.15
V	69.57	5.04	24.66	54.41
VI	64.60	5.44	29.55	59.16
VII	69.89	5.07	23.56	45.84
VIII	64.43	5.39	29.73	58.93
IX	69.59	5.19	24.78	53.55
X	67.40	5.47	24.71	56.97

At Coal Harbor, Unga of Dall's descriptions, in western Alaska, the analyses give for the coal, ash and water free: Carbon, 68.76; hydrogen, 5.30; oxygen and nitrogen, 24.89; volatile, 50.29.

[261] E. E. Smith, U. S. Geol. Survey, Bull. 474, 1911, pp. 42, 43, 48, 51, 64, 65, 66, 67.

On the borders of Kachemak Bay, farther east, ten samples were collected which have the composition shown in the preceding table, calculated after the same method:

Number VII. gives the composition of pebbles of lignite forming part of a conglomerate at the bottom of the Kenai (Eocene) in this district.

Nine samples were cut from the bed on Chicago Creek in the Seward Peninsula, which is 88 feet thick. In each case the sample represents a 12-feet cut. The results of analysis are:

	C.	H.	O and N.	Volatile.
I	71.69	5.01	22.18	44.84
II	71.25	4.85	23.02	45.89
III	70.78	5.05	22.96	44.96
IV	70.41	4.72	23.62	43.98
V	74.82	4.71	19.43	43.83
VI	69.33	4.61	24.41	44.70
VII	67.32	4.85	25.90	46.73
VIII	68.56	5.01	23.77	46.25
IX	68.68	4.83	24.46	46.51

In the Kachemak area the moisture in freshly mined coal varies from 17.44 to 28 per cent. and the ash is from 10.50 to 20.34 per cent. of the coal, dried at 105° C. But in one sample it is only 7.81. In the Chicago Creek bed the moisture is from 32 to 42 per cent. of the fresh coal and the ash is from 5.77 to 6.49 in dried coal from the upper half of the bed, as represented in analyses I. to IV., but in the remaining analyses it increases, becoming 9, 11, 31, 21 and 26 per cent., fractions being omitted.

The Kachemak analyses show that the carbon content varies from 64.60 to 69.59, but the volatile is from 50.86 to 64.44. Coals with almost exactly the same ultimate composition differ about 5 per cent. in the volatile. The Seward analyses prove great uniformity in composition of pure coal throughout the immense bed, the variation in carbon being only from 68 to 71, except in one cut, midway, where the maximum of 74 per cent. is reached. The volatile is greatest in the lowest third, where the ash is greatest; but there is no relation between the ash and the volatile; for in IX. the ash is 26.15 per cent. of the dry coal and the volatile is 46.51, while in VII. the ash

is 31.70 and the volatile is 46.73; in II. the ash is 5.77 and the volatile is 45.89.

Summary.—It is now in place to gather the facts presented and, if possible, to ascertain how far they may be related to the problem in hand.

The testimony throughout shows that Tertiary coal beds are notably limited in extent, their area varying from a few square rods to several hundreds of square miles—in some cases apparently even to 2,000 square miles; the extent being limited by the topography as the deposits appear, for the most part, to have accumulated in shallow ponds or in well-defined valleys. The lens-like form has been emphasized by almost all observers in every portion of the Tertiary. Unfortunately the details recorded for most localities are insufficient to justify an attempt at working out the history of any bed, known to exist within a large space. Detailed study is impossible at present in the United States and Canada, where alone the great beds are known, because those occur in regions with sparse population, where, for long distances, one must depend on imperfect natural outcrops or on the less definite lines of clinkered rock, caused by spontaneous combustion of the coal. The perplexity is increased by variations in thickness and composition of the intervening rocks, as well as by similar variations in the coal beds themselves, which make correlation extremely difficult. Several American observers decline to regard the coal deposits as continuous in large areas and prefer to describe "coal horizons." All agree as to the lens-like character of very many beds; even those who are unwilling to accept this for the great beds, frankly present the frequent changes into shale and the local disappearances of the coal as serious problems. Some observers have shown that the lenses often overlap, that a coal thins out and may be replaced by another at a few feet higher or lower. This feature, so characteristic of American localities, was recognized by Credner and by Raefler in the coals of Prussian Saxony.

The rocks intervening between beds of Tertiary coal may be conglomerate, gravel, sandstone, sand, shale, clay, limestone or alternations of such deposits. Ordinarily, these are of freshwater origin, but, not infrequently, one finds layers with brackish-water

fossils and occasionally a bed with typical marine forms. At most localities the bedding is irregular and the rocks seem, in many cases, to be composed of dove-tailing lenses; lenses of fine clay occur frequently. Sandstones and sands are cross-bedded in great areas; ripple-markings and mud-cracks have been reported from many places. Conditions in the western United States appear to indicate that these deposits were made on plains, where the sands drifted and where the water was collected in shallow pond-like areas. The gravels in many cases indicate filled channel-ways.

These intervening rocks frequently contain drifted materials. Leaves and stems of upland vegetation are found in the sands of Siberia; Collier saw cones of *Picea,* bones of mammals, land and freshwater shells in beds overlying Pliocene lignite on the Yukon; Grand'Eury observed wood, roots and spots of lignite at Budweis; Colenso in Wales described a deposit very like that of Alaska; the sections in western North America usually contain reference to these drifted plant remains. But not all the plant remains were transported; at many places they mark old soils of vegetation, surfaces where plants grew, but not long enough for accumulation of coal. There are many references to these in preceding pages and only one need be added. Darwin,[262] in a publication later than his "Researches," gave a detailed description of the petrified forest seen on the Uspallata range of Chili. The stumps, exposed in a small area, were in green and brown sandstone, which had been removed by erosion so as to show the erect stems in place. Fifty-two stumps were examined, projecting 3 to 5 feet—in one case 7 feet—from the surface. Whether or not they were rooted, he could not determine, as the lower part in every case was still buried in the rock. The dip was 25 degrees and the stems were vertical to the bedding. It was suggested to him that the trees might have been transported, but that explanation seemed insufficient; it might suffice for a single stump but not for a clump of 52 trees, which belonged to an inland coniferous flora, not to a coast vegetation. The conditions convinced him that erosion had laid bare only a small part of the forest.

Occasionally, lake marls, interrupted by beds of brown coal,

[262] C. Darwin, "Geological Observations in South America," London, 1846, pp. 202.

accumulated in great thickness, as in southern France. It is evident that some were made close to estuaries, for several observers have recorded that thick deposits, crowded with freshwater fossils, are interrupted by layers containing forms which are unquestionably marine. The intervals between Tertiary coal beds vary so greatly and so abruptly in thickness that, where natural exposures are the only dependence, correlation of beds in any area is difficult, often impossible.

The roof of a Tertiary coal bed may be composed of any kind of rock, transported or formed *in situ*. There are abundant illustrations of transition from the underlying coal to the roof rock, from accumulation of coal to final destruction of plant life on the bog surface, alternating laminæ of vegetable and mineral material testifying to the struggle between silt overflows and the dwindling bog. This faux-toit is a characteristic feature; at times it is merely a carbonaceous shale; at others it is a very impure coal. Very often the immediate roof is distinctly transported material with leaves, twigs and broken bits of wood, even fragmentary trunks of trees. It may be marine shale, rich in fossils, or it may be a marine limestone, as at Häring, containing bits of water-loving plants, such as *Salix, Erica* and palms. Or it may be sand enveloping erect trunks of trees, which grew on the dried surface of the bog, as at Senftenberg or near Friesdorf in the Cologne area. Grand'Eury[263] remarks that the fossil forest in the roof of the great coal bed at Petroszeny, in Hungary, rivals that of Purbeck and that the trunks, erect, are rooted on the top of the coal, while around the stems at the bottom of the deposit are branches of *Taxodium distichum*, clearly fallen from the stumps. A similar condition is reported from localities in the United States and in Europe. At times, the roots of trees growing in the faux-toit, pass downward into the coal as described by D. White for a mine in Texas and by other observers in places where the stumps are rooted in the coal. Grains of coal are not rare in the roof or the accompanying rocks, showing clearly that a coal deposit had been exposed to erosion. In much of the Oligocene areas of Prussia, the original roof has been removed and has been replaced with late drift material. The gradual disappearance of coal-forming

[263] C. Grand'Eury, *Comptes Rendus*, T. 130, 1900, p. 1689.

conditions is shown very frequently by a faux-toit; but not rarely the passage from coal to roof is abrupt, which may indicate, perhaps, that peat-making had ceased for some time prior to the burial under transported material.

The coal beds are rarely single; they are divided by partings into benches, which differ greatly in thickness and in composition, though there are beds which are remarkably uniform in composition throughout. The coal may be hard or soft, massive or laminated, and the several types may be in separate benches or even in the same bench. Generally, the coal is hard enough to require the use of heavy tools in mining so that it comes out in lumps, Knabben- or Knorpelkohle of the Germans. This type is especially characteristic in the United States. But in somewhat extensive areas within Germany one finds abundantly the other type, Form-, Fein-, Rieselkohle of the various localities, fine-grained, earthy in appearance and but slightly coherent. All types of coal, enumerated by authors, may be found in a single bed or even in a single bench. Fragments of wood are numerous, lignite at one end where the annual rings are distinct, while at the other end they have been converted in shining Pechkohle, apparently without trace of vegetable texture. A similar condition is seen in many cases of replacement, for one part of a stem may be wholly silicified while the other remains wood. In such cases, the original structure frequently remains distinct, whereas in replacement with dissolved carbon compounds, as in Pechkole, the structure disappears. The distribution of Formkohle in a bed is indefinite; it may occupy the whole space from floor to roof, interrupted only by partings; it may be at the bottom or at the top, or it may alternate with benches of other coals. Its mode of origin is discussed elsewhere by the writer.

Macroscopically, the coal consists of various fragments of organic and of inorganic origin, embedded in a structureless mass, in which the unaided eye can find no trace of texture; but under the microscope, this structureless mass proves to be minutely divided plant débris. Woody materials are often predominant, occasionally more than three fourths of the mass. Logs are reported from all localities, but they are distributed irregularly through the deposit, at least

as a rule. At times, prostrate stems as well as rooted stumps are abundant especially in the lower portions, but at others they occur within definite horizons in the higher portions; the smaller fragments are frequently converted into mineral charcoal. These conditions, observed in widely separated American localities, are similar to those observed in many European places, though, there, mases of logs are not so common as in the American lignitic coals; but the logs are found in all sorts of coal, Formkohle as well as Knorpelkohle and, many times, they are of enormous size. Prostrate logs are, with rare exceptions, compressed, often so compressed that it would seem as though only the bark remains, but erect stumps are very rarely compressed. Leaves and the strongly compressed stems appear as impressions on the structureless débris though occasionally, as at Bovey Tracey, leaves may form the great mass as slightly compressed logs do elsewhere. The logs belong mostly to conifers and they have been preserved because of the resin-content. The débris, formed from the softer, more readily decomposed plants and portions of plants, contains spores, pollen grains, bits of dicotyledonous plants as well as of the softer parts of conifers. The disintegration and decomposition of the material has led to enrichment in resins, as shown under the microscope. Replacement of wood is common, the replacing material being for the most part, silica, pyrite, calcium and ferrous carbonates; this replacement has been observed in the peaty material of the débris, giving the nodules, which Gothan and Hörich have termed torfdolomite.

Animal remains have been found in coal at many localities. Sedgwick and Murchison, as well as Anker, discovered bones of mammals in the Eocene bogs of Styria; Katzer saw teeth and bones of mammals in the Banjaluka coal; Fournet saw abundance of land and freshwater shells in the French lignite; v. Gümbel observed *Helix* in some layers of Pechkole in southern Bavaria. The dysodil or Blätterkohle of the Lower Rhine region contains many species of batrachians, fishes and insects, while that of southern France is closely packed with fish remains, retaining at some localities much of the original animal matter. Inorganic materials are normal constituents of coal; some of the admixture is due to silicious organisms,

for diatoms are of common occurrence, occasionally following important deposits; a greater proportion is derived from the mineral content of the coal-producing plants themselves; but when the quantity is considerable, the most of it is of extraneous origin. Pockets of sand and silt have been reported by almost all observers. The silt is often distributed intimately throughout the coal or it may be collected in thin laminæ, such as render the coal worthless, or it may be in comparatively thick partings; even pebbles of rock have been reported from a few localities.

Brown coal deposits, with rare exceptions, are broken by partings. These may be so thin as hardly to be seen by the unaided eye, yet they are distinct, for the coal separates on their planes; they may be a foot or more in thickness and composed of any material transported or formed in place. Each definite parting is roof to the underlying, and floor to the overlying coal. Roots, leaves and freshwater, as well as land shells have been reported from clay partings in Hungary and Bosnia, leaves from New Zealand and Borneo and freshwater shells from shale and marly limestone partings in France. References to other regions are in preceding pages. Each parting is evidence of interrupted coal-accumulation; but its thickness at any place is no evidence respecting the duration of the period of interruption, for the thickness is a variable quantity. Russwurm notes a parting which increases from 0.5 to 4 meters within a short distance; near Gran in Hungary is one which is 1.9 meter in one mine but 17.45 meters in another, only a little way off; Evans has described one in Washington, which thickens from 4 to 90 feet within a horizontal distance of 3,200 feet, while in another direction it quickly decreases to 10 inches. Such variations are due to merely local causes as the deposits, for the most part, are of very limited extent. The changes are comparable to those observed in the rocks intervening between coal beds, often so great as to make correlation of the coals difficult. The partings, which consist largely of mineral charcoal, are important, as they appear to be often persistent throughout a basin; yet they are rarely more than half an inch thick. These indicate a positive change in conditions which made growth of vegetation imposible and led to exposure of the peaty surface to atmospheric

action. A layer of mineral charcoal and minutely divided inorganic matter may be the residuum from a considerable thickness of peat; the proportion converted into mineral charcoal and so rendered practically indestructible would be small compared with that wasted by oxidation and removed by the wind.

Evidence of long-continued interruption of ordinary peat formation is afforded by forest beds within the coal deposit. At Senftenberg, as shown by Potonié, the surface of the bog became dry enough, more than once, to permit growth of trees; in the Cologne-Linz area, the dryness was such and the period so long that a forest, containing trees with 1,600 annual rings, had full opportunity for development. In much of the Cologne region, the vast proportion of the stems are prostrate, but that condition is by no means evidence that they are in any but the place of growth. They are merely overturned trees as are those of the white cedar swamps of New Jersey or those in the cypress swamps of Florida or the bogs of Borneo. One layer in the Cologne-Linz district is a meter thick but erect stumps are present among the prostrate stems, as Horner and Heusler have shown. Trees of such immense size as those described by Horner indicate a very prolonged period of comparative dryness, during which the peat, as soil for the trees, was protected from wasting by offal dropping from the dense forest cover. A somewhat similar condition was noted by Wegemann in the Barber coal field of Wyoming.

The floor of coal beds is as variable as the roof, but it is usually clay or marl. The transition from the coal is occasionally abrupt, but in most cases the passage is gradual, through a faux-mur, consisting of alternating layers of coaly material and the mur rock. Very frequently the mur contains fresh water shells, that condition being reported from many places in all parts of the world. Land shells are not rare; they may have been floated in or they may mark drier places in the swamp. Leaves are found frequently in the marls and clays. The notable feature of the mur is the presence of roots attached to stems projecting into the overlying coal. At times the roots alone remain recognizable, the stems having been merged in the coal. Usually these are those of swamp types; but in cases

where the stumps project into the coal other forms may occur. The classic illustration is that at Senftenberg, described by Potonié, where one sees complete evidence of destruction of a forest by a transgressing bog. Kukuk's photograph of wholly similar conditions is equally conclusive. Not rarely the stumps had become hollow before entombment.

No complete statement respecting the flora of the brown coals can be made; the plants obtained from the associated rocks cannot be utilized as they are enclosed in rocks of transported material and represent, in part at least, the upland flora; they are as inconclusive as would be lists of forms found in the clays and sands which had slipped down on a swamp, to one endeavoring to determine the plants of peat. It is necessary to confine one's investigation to such information as can be obtained from the coal itself, though in some cases evidence from the enclosing shales may be utilized as illustrating prevailing conditions in the immediate vicinity.

The logs and stumps within the coal beds are almost invariably conifers. In Greenland and Spitzbergen, recognizable remains are rare in the coal and the logs are usually silicified; but the associated shale shows that, during its deposition, the prevalent types of the immediate vicinity were conifers and other forms of acid-loving plants, a swamp flora, so that swampy conditions prevailed in the area whence the shale material was drawn. The Pliocene coal of Hungary is crowded with stems of *Sequoia;* the Miocene swamp of Virginia contains *Taxodium, Nyssa, Salix, Quercus* and other types belonging to genera familiar in recent cypress swamps. At Bovey Tracey in the Eocene, ferns and *Sequoia* predominate, yet at the bottom of one bench there is a mass of dicotyledonous leaves. Fournet found a typical swamp flora in the Vion lignite, where he recognized birch, juniper, fir, cherry and walnut, with sedges and rushes. Daubrée, near Lobsann on the Lower Rhine, found that the mineral charcoal is from conifers while the peculiar fibrous coal, his lignite bacillaire, which forms the greater part of some deposits, is derived from Palms. At Senftenberg *Taxodium distichum* is the prevailing type in the coal, but in the upper layer are stumps of *Pinus* or *Picea.* Conifers and palms are the most abundant types in

the Hardt district of the Cologne-Linz region. The woody fragments in Brandenburg mines are practically all from conifers; in Sachsen, the fossil wood is coniferous, belonging almost wholly to the cypresses; but at Tanndorf, where the conditions are well shown, Penck found *Salvinia* and *Trapa* in the lower portions, succeeded by a layer with *Arundo,* which is followed by normal peat with *Betula* and *Palmacites.* Reuss's collections from the fetid limestone roof of the Häring coal show that the coal was formed at the head of an estuary for, mingled with remains of marine animals, it contained abundant fragmentary remains of *Salix, Erica,* palms and other swamp plants, which, it would seem, must have been torn away from the still living swamp on the shore, continuous with the buried swamp which has given the Häring coal. American localities tell the same story respecting the woody materials. Grand'Eury,[264] in summing up the results of his studies, asserted that in the lignite areas of Tertiary age he had found as many stumps with roots and branches *in situ,* as in Carboniferous coal basins. From their position, even in the midst of rocks and limestones, it is to be presumed that the *in situ* roots are evidence of plants growing on bottoms subject to inundation. The flora shows instances of local variation, one striking illustration being that recorded by Heusler in the Cologne area.

Very few observers have given detailed record of localities where evidences of contemporaneous erosion are distinct. The writer has made careful comparison of sections preserved in basins of considerable magnitude and he is convinced that the variations in coal and the intervening rocks are such in many areas that they can be explained as due only to contemporaneous erosion. The absolute proof of such erosion cannot be secured except where coal mining has been well-developed—and there are few such localities in the American Tertiary. European basins are small and the petty variations due to contemporaneous erosion are easily overlooked. Very clear cases of such erosion have been reported from the interval rocks of Wyoming but in no case is the extent fully revealed. Evans has shown that in Washington some coal beds have suffered severely

[264] C. Grand'Eury, *Comptes Rendus,* T. 138, 1904, pp. 666 ff., 740 ff.

and that, in considerable spaces, the coal has been removed and has been replaced with sandstone.

The intimate resemblance of many brown coal deposits to those of peat has been affirmed by many observers. Collier recognized the resemblance in Alaska and Washington as did Eldridge in Alaska; Haast was positive respecting it in southern New Zealand; several authors have described the Moor- and Mooskohle of Prussia and Bohemia; Gothan and Hörich have shown that the Torfdolomite of the Lower Rhine is merely mature peat replaced by inorganic matter; Smith and Travers[265] described as peat an impure brown coal underlying the London clay. In many places the coal has been found resting on the characteristic reed beds.

Few students have made minute investigation of the structure and succssion of individual beds. Penck's observations at Tanndorf have made clear that the brown coal at that place is in a lake basin; the muddy floor afforded roothold for floating plants, on whose débris rushes and other plants of similar habit grew, until the surface became such as to permit growth of shrubs and trees. Others have reported the occurrence of swamp plants in the brown coal, but they have not said anything about their vertical distribution in the deposit. Similarly, the presence of land and freshwater shells has been noted by numerous writers, but there is rarely any information as to their distribution in the bed. All that one may assert is that these indicate the existence of pools or ponds in the marsh. Expansion of the accumulating area by transgression, after the manner of swamps, is distinct at many places. Stohr has shown that in a part of Prussian Sachsen, the deposit began on an irregular surface as a number of separate lenses, which often became united by crossing the dividing ridges; so that the coal is from 0 to 20 meters thick, being thinnest on the low rolls separating the narrow troughs. D. White's description of conditions at Lehigh, North Dakota, is wholly similar; the greatest thickness is in the hollows of the floor and the coal becomes thinner toward the "rise." At Senftenberg and Orebkau, as appears from description by Potonié and Russwurm, transgression upon forests is clear. At Senftenberg, the forest was living when the marsh

[265] W. Smith and M. W. Travers, *Journ. Soc. Chem. Ind.*, Vol. XI., 1892, p. 591.

invaded it, and the stems, still erect, extend into the coal; but at Orebkau, the condition appears to have been different. There, logs increase downward until at the bottom they constitute practically the whole mass. The forest growing in loose material must have been overthrown, for in the mines examined by Russwurm, no erect stems were seen. Many beds of brown coal seem to be wholly without tree trunks, just as there are many peat bogs without fragments larger than a twig; these had not reached the stage of tree-growth. Interruptions in growth are equally characteristic of peat bogs and brown coal beds. Some are shown by partings containing much mineral charcoal, others by partings of transported mineral matter, while others still by the forest layers. At Bovey Tracey, a great mass of leaves in the lower part of a thick bench is the remaining evidence of a dicotyledonous forest, whose non-resinous stems have disappeared. A succession of forests is shown at Senftenberg, even to the last, which was entombed in the covering sands as was that at Wurzen in Sachsen. The great forest bed of the Hardt area marks a long, though not total interruption; growth of normal peat ceased for the time, but accumulation most probably continued; offal from coniferous trees accumulates to notable thickness in many parts of the world without injury to the trees; Capps has shown that in Alaska, where the plane of perpetual frost is at only a few inches below the surface, the gigantic spruces adjust themselves to the conditions and throw out new sets of roots as the peat surface rises.

The benches of a coal bed often are dissimilar. One finds no evidence of widespread climatic changes during the period of a single bed's growth. In most cases, there is evidence of notable variation in moisture conditions and dryness appears in some localities to have prevailed for long periods; but there is no evidence that these variations were due to any but local causes. They are much like those which may be seen in almost every peat deposit. At Bovey Tracey, one bench is composed almost wholly of fronds of ferns while another is a mass of *Sequoia* stems; near Budweis, the upper bench contains stems completely coaled, while the lower bench is composed mostly of the imperfectly changed Moorkohle. Hantken has described a bed of which the upper part is woody, crowded with

Sequoia, while the lower part is hard coal. At Orebkau, the upper bench is Knorpelkohle, with very little wood, while the lower bench is Formkohle with much wood. Variations of similar type are reported from American localities and they are such as are familiar to students of peat deposits. They are so characteristic that one finds it difficult to avoid the conclusion that, as in peat bogs, the process of conversion was arrested in some benches while it continued in others. It seems hardly possible that the differences developed after burial, as conditions since that time must have been practically the same for all portions of the deposit.

The differences in physical features are accompanied by differences in chemical composition. The lower portion of the coal bed on Advent Bay, Spitzbergen, has 9 per cent. more volatile than is found in the upper portion. Coals from different parts of the same mine show even greater contrast; 18 per cent. near Gran in Hungary, 23 near Brennberg in the same kingdom, 35 at Glendive in Montana; and similar variations are shown by analyses of samples from neighboring mines on the same bed. The ash content tells the same story; in six mines on the same bed, near Rockdale, Texas, the ash varies from 9.43 to 24.67. The comparison is more instructive when one considers the composition of the ash, for the samples analyzed were prisms representing the full thickness of the seam, only such partings being removed as should be separated before shipment of the coal. The silica is from 21 to 47 per cent., alumina from 12 to 28, ferrous oxide from 2 to almost 25, lime 6 to 38 and sulphuric acid 4.58 to 18.01. These samples were taken in an area of probably not more than 2 or 3 square miles. It would appear that conditions during accumulation varied greatly in the different parts of even small areas, just as they do in the swamp areas of this day.

Sapropelic or Lebertorf material is an important constituent of many swamps, though there are very many in which no trace of it exists. It has been reported occasionally from the Tertiary coal. Dall obtained at Amalik Harbor, Alaska, a dull coal which contains 81.26 per cent. of volatile matter; at Mendota in Washington there are lenses of what appears to be Lebertorf, the coal having all the features of cannel and burning with a long smoky flame; lenses of

wholly similar material were observed by D. White at Hoyt, Texas; the same observer has described the cannel-like material of the Lester bed in Arkansas, very rich in oils and in gas of high candle-power; it is rich also in spores and pollen exines. Tertiary "oil shale" of high grade is reported from New Zealand. The mode of occurrence and the chemical as well as physical constitution indicate very close relationship to the Lebertorfs. Pyropissite presents some problems not yet wholly solved, though they have attracted attention from many students; but there appears to be little evidence to support the hypothesis that it is merely the resin of the original plants, concentrated by physical agencies during transportation of the more or less converted peat or brown coal; while there is much to suggest that it is related to the Lebertorfs. The condition is different in the case of dysodil or Blätterkohle; that is without doubt of sapropelic origin. It occurs in lenses, sometimes at the bottom, at others in the upper portion of a bed, while, occasionally, it forms the whole mass. This contains abundant remains of aquatic animals, spores, pollen and, at times, is rendered almost worthless by the great proportion of diatomaceous earth.

Haidinger, in studying the Faserkohle from the Häring deposit, discovered that it contained a material, which he believed was introduced when in the condition of dopplerite, a soluble constituent of peat; D. White in several publications has maintained that the jetified wood, so abundant in the xyloid Tertiary coals of the United States, owes its character to the infiltration of dissolved products of vegetable decomposition. Glöckner reached the same conclusion respecting the "Glanzkohle" of Zittau. Von Gümbel regarded the "Carbohumin" or cementing material of brown coal as merely dopplerite which had passed over to the insoluble condition. Dopplerite, as the analyses show, is not a true mineral but is a mixture of various humic or humic and ulmic compounds, which after losing an indefinite proportion of water, is so changed that it cannot regain plasticity even by prolonged submergence in water. The zittavite of Glöckner appears to be a wholly similar substance; the terms dopplerite, Carbohumin and zittavite indicate the geological horizons of the occurrence.

The carbon content of brown coal varies; in a general way it gives proof of great advance over peat, yet in many localities the process of conversion stopped short of the stage reached by most of the fuel peats of which analyses are available. Pliocene coal of Bavaria has from 62 to 69 per cent.; Miocene coal from one mine in Bavaria has but 49, the Édéleny coal of Hungary has but 54 and the Grottauer coal in Bohemia has 53; but in other localities in Bavaria the carbon is almost 71 and near Brennberg in Hungary it is 72. The Oligocene coal in the Gran-Comorn district of Hungary shows 65 to almost 74; the Brandenburg coals have 60 to almost 71, the Zeitz area of Sachsen 64.78, and the Cologne area only 62. Eocene coal of Bovey Tracey has almost 70; coal at Rockdale, Texas, contains 67.36 to 77.11 in samples from several mines on the same bed. In the northern areas within the United States, there are few analyses showing less than 70 and some reach 75, but in Alaska coal from most of the beds has from 64 to 70. In Alaska and Washington, there are localities where the carbon content is much higher, but those do not concern the matter in hand, as there is reason to look upon them as more or less metamorphosed.

Beyond all question, there is at most localities distinct evidence of progressive enrichment in carbon with loss of oxygen as one descends in the scale. The extremes of carbon content in peat are 40 and 64; in the Miocene, 49 to 72; in the Oligocene, 58 and 70, in the Eocene, 64 to 79. At the same time one must recognize that, as in peat deposits, the progress of change was checked in some localities at a much earlier stage than in others.